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ANNUAL REPORT OF THE
BOARD OF REGENTS OF
THE SMITHSONIAN
INSTITUTION

SHOWING THE
OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDED JUNE 30

1947



(Publication 3921)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1948

LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, February 13, 1948.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1947. I have the honor to be,

Respectfully,

A. WETMORE, *Secretary.*

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THE SMITHSONIAN INSTITUTION

June 30, 1947

Presiding Officer ex officio.—HARRY S. TRUMAN, President of the United States.

Chancellor.—FRED M. VINSON, Chief Justice of the United States.

Members of the Institution:

HARRY S. TRUMAN, President of the United States.

—— Vice President of the United States.

FRED M. VINSON, Chief Justice of the United States.

GEORGE C. MARSHALL, Secretary of State.

JOHN W. SNYDER, Secretary of the Treasury.

ROBERT P. PATTERSON, Secretary of War.

TOM C. CLARK, Attorney General.

ROBERT E. HANNEGAN, Postmaster General.

JAMES FORBES, Secretary of the Navy.

JULIUS A. KRUG, Secretary of the Interior.

CLINTON P. ANDERSON, Secretary of Agriculture.

WILLIAM AVERELL HARRIMAN, Secretary of Commerce.

LEWIS B. SCHWELLENBACH, Secretary of Labor.

Regents of the Institution:

FRED M. VINSON, Chief Justice of the United States, Chancellor.

—— Vice President of the United States.

ALBEN W. BARKLEY, Member of the Senate.

WALLACE H. WHITE, Jr., Member of the Senate.

WALTER F. GEORGE, Member of the Senate.

CLARENCE CANNON, Member of the House of Representatives.

SAMUEL K. McCONNELL, Jr., Member of the House of Representatives.

JOHN M. VOYSE, Member of the House of Representatives.

FREDERIC A. DELANO, citizen of Washington, D. C.

HARVEY N. DAVIS, citizen of New Jersey.

ARTHUR H. COMPTON, citizen of Missouri.

VANNEVAR BUSH, citizen of Washington, D. C.

FREDERIC C. WALCOTT, citizen of Connecticut.

Executive Committee.—FREDERIC A. DELANO, VANNEVAR BUSH, CLARENCE CANNON.

Secretary.—ALEXANDER WETMORE.

Assistant Secretary.—JOHN E. GRAF.

Assistant Secretary.—J. L. KEDDY.

Administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer.—NICHOLAS W. DORSEY.

Chief, editorial division.—WEBSTER P. TRUE.

Librarian.—LEILA F. CLARK.

Administrative accountant.—THOMAS F. CLARK.

Personnel officer.—BERTHA T. CARWITHEN.

Chief, publications division.—L. E. COMMERFORD.

Purchasing officer.—ANTHONY W. WILDING.

UNITED STATES NATIONAL MUSEUM

Director.—ALEXANDER WETMORE.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Frank M. Setzler, head curator; A. J. Andrews, chief preparator.

Division of Archeology: Neil M. Judd, curator; Waldo R. Wedel, associate curator; J. R. Caldwell, scientific aid; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Ethnology: H. W. Krieger, curator; J. C. Ewers, associate curator; R. A. Elder, Jr., assistant curator; Arthur P. Rice, collaborator.

Division of Physical Anthropology: T. Dale Stewart, curator; M. T. Newman, associate curator.

Collaborators in anthropology: George Grant MacCurdy, W. W. Taylor, Jr.

DEPARTMENT OF BIOLOGY:

Waldo L. Schmitt, head curator; W. L. Brown, chief taxidermist; Aime M. Awl, illustrator.

Division of Mammals: Remington Kellogg, curator; D. H. Johnson, associate curator; A. Brazier Howell, collaborator; Gerrit S. Miller, Jr., associate.

Division of Birds: Herbert Friedmann, curator; H. G. Deignan, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Doris M. Cochran, associate curator.

Division of Fishes: Leonard P. Schultz, curator; R. R. Miller, associate curator; D. S. Erdman, scientific aid.

Division of Insects: L. O. Howard, honorary curator; Edward A. Chapin, curator; R. E. Blackwelder, associate curator; W. E. Hoffmann, associate curator; W. L. Jellison, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: F. A. Chace, Jr., curator; P. L. Ilg, associate curator; Frederick M. Bayer, assistant curator; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; J. Percy Moore, collaborator; Joseph A. Cushman, collaborator in Foraminifera; Mrs. M. S. Wilson, collaborator in copepod Crustacea.

Division of Mollusks: Harald A. Rehder, curator; Joseph P. E. Morrison, associate curator; R. Tucker Abbott, assistant curator; P. Bartsch, associate.

Section of Helminthological Collections: Benjamin Schwartz, collaborator.

Division of Echinoderms: Austin H. Clark, curator.

DEPARTMENT OF BIOLOGY—Continued

Division of Plants (National Herbarium): E. P. Killip, curator; Emery C. Leonard, associate curator; Conrad V. Morton, associate curator; Egbert H. Walker, associate curator; John A. Stevenson, custodian of C. G. Lloyd mycological collection; Agnes Chase, research associate.

Section of Grasses: J. R. Swallen, associate curator.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

Section of Lower Fungi: D. G. Fairchild, custodian.

Section of Diatoms: Paul S. Conger, associate curator.

Associates in Zoology: Theodore S. Palmer, William B. Marshall, A. G. Böying, W. K. Fisher, C. R. Shoemaker.

Associates in Botany: Henri Pittier, F. A. McClure, W. R. Maxon.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

DEPARTMENT OF GEOLOGY:

R. S. Bassler, head curator; J. H. Benn, exhibits preparator; Jessie G. Beach, aid.

Division of Mineralogy and Petrology: W. F. Foshag, curator; E. P. Henderson, associate curator; B. O. Reberholt, exhibits preparator; Frank L. Hess, custodian of rare metals and rare earths.

Division of Invertebrate Paleontology and Paleobotany: Gustav A. Cooper, curator; A. R. Loeblich, Jr., associate curator; J. Brookes Knight, research associate in Paleontology.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; J. B. Reeside, Jr., custodian of Mesozoic collection.

Division of Vertebrate Paleontology: C. L. Gazin, curator; D. H. Dunkle, associate curator; Norman H. Boss, chief exhibits preparator; A. C. Murray, scientific aid; F. L. Pearce, preparator.

Associates in Mineralogy: W. T. Schaller, S. H. Perry.

Associate in Paleontology: T. W. Vaughan.

Associate in Petrology: Whitman Cross.

DEPARTMENT OF ENGINEERING AND INDUSTRIES:

Carl W. Mitman, head curator.

Division of Engineering: Frank A. Taylor, curator; K. M. Perry, exhibits preparator.

Section of Civil and Mechanical Engineering: Frank A. Taylor, in charge.

Section of Marine Transportation: Frank A. Taylor, in charge.

Section of Electricity: Frank A. Taylor, in charge.

Section of Physical Sciences and Measurement: Frank A. Taylor, in charge.

Section of Land Transportation: S. H. Oliver, associate curator.

Division of Aeronautics: P. E. Garber, curator.

Division of Crafts and Industries: W. N. Watkins, curator; F. C. Reed, associate curator; E. A. Avery, museum aid; F. L. Lewton, research associate.

Section of Textiles: M. M. Windhorst, assistant curator.

Section of Wood Technology: William N. Watkins, in charge.

Section of Manufactures: F. C. Reed, in charge.

Section of Agricultural Industries: F. C. Reed, in charge.

Division of Medicine and Public Health: Charles Whitebread, curator.

Division of Graphic Arts: J. Kalnen, curator; E. J. Fite, museum aid.

Section of Photography: A. J. Wedderburn, Jr., associate curator.

DIVISION OF HISTORY: T. T. Belote, curator; Charles Carey, associate curator; M. W. Brown, assistant curator; J. Russell Sirlouis, scientific aid.
Section of Civil History: T. T. Belote, in charge.
Section of Military History: C. Carey, in charge.
Section of Naval History: C. Carey, in charge.
Section of Numismatics: T. T. Belote, in charge.
Section of Philately: C. L. Manning, assistant curator.

ADMINISTRATIVE STAFF

Chief, office of correspondence and records.—H. S. BRYANT.
Superintendent of buildings and labor.—L. L. OLIVER.
Assistant superintendent of buildings and labor.—CHARLES C. SINCLAIR.
Editor.—PAUL H. OEHSE.
Accountant and auditor.—T. F. CLARK.
Photographer.—G. I. HIGHTOWER.
Purchasing officer.—A. W. WILDING.
Assistant librarian.—ELISABETH H. GAZIN.

NATIONAL GALLERY OF ART

Trustees:

FRED M. VINSON, Chief Justice of the United States, *Chairman*.
GEORGE C. MARSHALL, Secretary of State.
JOHN W. SNYDER, Secretary of the Treasury.
ALEXANDER WETMORE, Secretary of the Smithsonian Institution.
SAMUEL H. KRESS.
FERDINAND LAMMOT BELIN.
DUNCAN PHILLIPS.
CHESTER DALE.
PAUL MELLON.

President.—SAMUEL H. KRESS.
Vice President.—FERDINAND LAMMOT BELIN.
Secretary-Treasurer.—HUNTINGTON CAIRNS.
Director.—DAVID E. FINLEY.
Administrator.—HARRY A. MCBRIDE.
General Counsel.—HUNTINGTON CAIRNS.
Chief Curator.—JOHN WALKER.
Assistant Director.—MACGILL JAMES.

NATIONAL COLLECTION OF FINE ARTS

Director.—RUEL P. TOLMAN; G. J. MARTIN, exhibits preparator.

FREER GALLERY OF ART

Director.—A. G. WENLEY.
Assistant Director.—J. A. POPE.
Research Associate.—GRACE DUNHAM GUEST.
Associate in Near Eastern art.—RICHARD ETTINGHAUSEN.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.
Associate Chief.—FRANK H. H. ROBERTS, JR.
Senior ethnologists.—H. B. COLLINS, JR., JOHN P. HARRINGTON, W. N. FENTON.
Senior anthropologists.—G. R. WILLEY; P. DRUCKER.

Collaborator.—JOHN R. SWANTON.

Editor.—M. HELEN PALMER.

Librarian.—MIRIAM B. KETCHUM.

Illustrator.—EDWIN G. CASSEDY.

INSTITUTE OF SOCIAL ANTHROPOLOGY.—G. M. FOSTER, Jr., *Director*.

RIVER BASIN SURVEYS.—FRANK H. H. ROBERTS, Jr., *Director in charge*.

INTERNATIONAL EXCHANGE SERVICE

Acting Chief.—HARRY W. DORSEY.

Chief Clerk.—D. G. WILLIAMS.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.

Assistant Director.—ERNEST P. WALKER.

Head Keeper.—FRANK O. LOWE.

ASTROPHYSICAL OBSERVATORY

Director.—LOYAL B. ALDRICH.

DIVISION OF ASTROPHYSICAL RESEARCH: Loyal B. Aldrich, chief; William H. Hoover, senior astrophysicist; Charles G. Abbot, research associate.

DIVISION OF RADIATION AND ORGANISMS: Earl S. Johnston, chief; Leland B. Clark, engineer (precision instruments); Robert L. Weintraub, chemist (biological); Leonard Price, junior physicist (biophysics); G. D. Talbert, instrument maker.

NATIONAL AIR MUSEUM

Advisory Board:

ALEXANDER WETMORE, *Chairman*.

MAJ. GEN. E. M. POWERS, *U. S. Army Air Forces*.

REAR ADM. A. M. PRIDE, *U. S. Navy*.

GROVER LOENING.

WILLIAM B. STOUT.

CANAL ZONE BIOLOGICAL AREA

Resident Manager.—JAMES ZETEK.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

ALEXANDER WETMORE

FOR THE YEAR ENDED JUNE 30, 1947

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and its bureaus during the fiscal year ended June 30, 1947. Appendixes 1 to 12 give detailed reports of the operations of the National Museum, the National Gallery of Art, the National Collection of Fine Arts, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the National Air Museum, the Canal Zone Biological Area, the Smithsonian library, and of the publications issued under the direction of the Institution. On page 162 is the financial report of the executive committee of the Board of Regents.

The purpose of the Institution, as stated in the will of its founder, is "the increase and diffusion of knowledge among men." The increase of knowledge is accomplished by means of scientific research and exploration, the diffusion of knowledge by its several series of publications, its International Exchange Service, its museum and art gallery exhibits, and various other means. As the Institution operates chiefly through the bureaus that have grown up around it as a result of its early work, the year's research and exploration will be found recorded in the reports of those bureaus, particularly the National Museum, the Bureau of American Ethnology, and the Astrophysical Observatory. A complete account of the year's publications appears in the report of the chief of the editorial division, appendix 12.

The fiscal year here reported upon is the first in the Institution's second century of existence. At the beginning of a new era, it is gratifying to report that a large part of the normal research and field work that had to be suspended during the war is now being resumed and, in certain lines, expanded. This is the first annual account in which appear reports on the newly established National Air Museum and on the Canal Zone Biological Area, recently placed under the Institution's administration. The number of visitors to the National Museum, the Freer Gallery of Art, and the National Zoological Park

is back to prewar levels, as is the number of accessions to the Museum collections. The International Exchange Service has made large inroads into the great accumulation of material for foreign exchange that built up during the war years, and the service will soon be again on a wholly current basis.

The two greatest needs of the Institution as stated in my last report are for more personnel and more building space. New buildings must, of course, await more propitious economic conditions, but plans are already outlined and the future outlook is hopeful. Strong presentations of the personnel shortage, particularly in scientific positions, are being made to the Bureau of the Budget and to Congress, with promise of relief in this direction also.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

During the year the following changes occurred in the personnel of the Board of Regents:

January 17, 1947: Chief Justice Vinson was elected Chancellor of the Institution.

January 27, 1947: Representative John M. Vorys, of Ohio, was appointed to finish the unexpired term of Representative B. Carroll Reece.

January 27, 1947: Representative Samuel K. McConnell, Jr., of Pennsylvania, was appointed to finish the unexpired term of Representative E. E. Cox.

The roll of regents at the close of the fiscal year June 30, 1947, was as follows:

Chief Justice Fred M. Vinson, Chancellor; members from the Senate, Alben W. Barkley, Wallace H. White, Jr., Walter F. George; members from the House of Representatives, Clarence Cannon, John M. Vorys, Samuel K. McConnell, Jr.; citizen members, Frederic A. Delano, Washington, D. C., Harvey N. Davis, New Jersey, Arthur H. Comp-

ton, Missouri, Vannevar Bush, Washington, D. C., and Frederic C. Walcott, Connecticut.

Proceedings.—The Board of Regents held its annual meeting on January 17, 1947, with the following members present: Senator Walter F. George, Representative Clarence Cannon, Dr. Vannevar Bush, Dr. Arthur H. Compton, Dr. Harvey N. Davis, Frederic A. Delano, the Secretary, Dr. Alexander Wetmore, and the Assistant Secretary, John E. Graf.

The Secretary presented his annual report covering the activities of the parent institution and of its several branches, including the financial report of the Executive Committee, for the fiscal year ended June 30, 1946, which was accepted by the Board. The usual resolution authorizing the expenditure by the Secretary of the income of the Institution for the fiscal year ending June 30, 1948, was adopted by the Board.

The gift of Miss Annie-May Hegeman was mentioned last year as amounting in total to \$300,000, being one-half the amount from the sale of the Porter property at the corner of Sixteenth and Eye Streets NW. The Library Trust Fund Board of the Library of Congress, which handled this matter, during the year forwarded a check for \$275,000 on this account, approximately \$25,000 being held temporarily, pending settlement of claim for sales commission on the part of real-estate brokers.

John A. Roebbling made a generous gift to the Institution in further support of the work of the Astrophysical Observatory.

On August 12, 1946, President Truman signed the act (Public Law 722) establishing the National Air Museum under the Smithsonian Institution. Under this act there is set up an advisory board composed of the Commanding General of the Army Air Forces, the Chief of Naval Operations, the Secretary of the Smithsonian Institution, and two citizens appointed by the President. General Spaatz, Chief of the Army Air Forces, has designated Maj. Gen. Edward M. Powers to represent him; Admiral Nimitz, Chief of Naval Operations, designated Rear Adm. H. B. Sallada; and the President, early in December, appointed Grover Loening and William B. Stout, both well known for their work in aviation, as the citizen members of the board. Subsequently, Admiral Nimitz assigned Rear Adm. Sallada to other duties and designated Rear Adm. A. M. Pride to represent him on the board.

The first meeting of the Advisory Board was held December 16, 1946, at which the Secretary of the Smithsonian Institution was elected Chairman. Discussions covered the scope, probable size, and location of the Museum. It was the opinion that these could be determined only after a complete survey of material of value for the Museum. The Chairman was instructed to prepare estimates for the \$50,000

authorized by the act for a survey, this to cover the latter part of the fiscal year 1947, and the year 1948, and to include travel funds and necessary assistance. In view of the great growth in aviation the new agency is one of major importance for preservation of historical material in aeronautics, both for public display and for study and examination by engineers and students of aerodynamics.

Under Reorganization Plan No. 3 of 1946, which became effective July 16, 1946, the President placed under the direction of the Smithsonian Institution the biological laboratory known as the Canal Zone Biological Area located in the Canal Zone, Panamá. When Gatun Lake was formed during construction of the Panama Canal, the impounded waters flowed around hills that stood in the valley, changing certain of them to islands. One of these, which became known as Barro Colorado Island, was notable for its fine stand of primitive tropical forest, and for the animal life confined on it by the waters of the lake. On April 17, 1923, Gov. Jay J. Morrow of the Canal Zone set aside Barro Colorado Island as a reserve, and on it there was established a field laboratory at which investigators might live and work on scientific problems concerned with a tropical jungle. This laboratory has been supported by small contributions from various agencies, including Harvard College, the University of Michigan, the Smithsonian Institution, and various others.

So much valuable scientific work came from this laboratory that the Congress set it aside permanently as a reserve under the name Canal Zone Biological Area, in an act effective July 2, 1940, as an independent agency under a Board of Directors composed of the Secretaries of War, Agriculture, Interior, and the Smithsonian Institution, the President of the National Academy of Sciences, and three distinguished biologists appointed by the President of the National Academy as Chairman of the Board. In the process of unification of governmental agencies, the Canal Zone Biological Area has now become a part of the Smithsonian, where it will be administered under the office of the Secretary. The reorganization plan abolished the former Board as the controlling body, but it has seemed desirable to continue this as an advisory board composed of representatives of the departments originally concerned, to secure desired support and cooperation for the activity.

Barro Colorado Island has been the site of a wide variety of studies and tests under tropical conditions. Those under way at the present time include an extensive set-up for testing termite-proofing of wood samples, tropical deterioration of plywoods, textiles, and packaging containers, and the effect of fungi on optical glass. Biologists come regularly to the island to make studies of the fauna and flora. Some 400 publications have been issued on research carried on here in the

fields of entomology, forestry, and medicine, with special reference to the control of termites, fruit flies, and mosquitoes.

The annual report of the Smithsonian Art Commission was presented by the Secretary and accepted by the Board. The Commission, at its meeting on December 6, 1946, accepted several works of art, including 23 miniatures. A resolution was adopted to reelect the following members for 4-year terms: John Taylor Arms, Gifford Beal, and Gilmore D. Clarke. Vacancies on the commission were caused by the resignations of Louis Ayres and Frank J. Mather. The names of William T. Aldrich and Lloyd Goodrich, recommended by the Commission, were approved to fill the above vacancies. The following officers were reelected for the ensuing year: Chairman, Paul Manship; Secretary, Alexander Wetmore.

The bill that was introduced in the House of Representatives (H. R. 2015 and H. Res. 139, 78th Cong., 2d sess.) for the relief of the estate of John Gellatly and/or Charleyne Whiteley Gellatly, his widow, was referred by the House, mentioned above as House Resolution 139, to the Court of Claims to ascertain the facts and make recommendations. The Court of Claims in an opinion dated May 5, 1947, stated that "there is no basis in law or in equity to set aside the gift or transfer and no basis in law or equity to allow a recovery in behalf of the Gellatly estate."

The Secretary brought to the attention of the Board the proposition to request the Civil Service Commission to extend the provisions of the Federal Classification Act to Smithsonian employees paid from trust funds. This proposal was approved by the Board under certain conditions.

APPROPRIATIONS

Funds appropriated to the Institution for the fiscal year ended June 30, 1947, totaled \$1,632,912, allotted as follows:

General administration	\$88,366
National Museum	530,068
Bureau of American Ethnology	76,366
Astrophysical Observatory	67,596
National Collection of Fine Arts	24,264
International Exchange Service	55,632
Maintenance and operation	632,377
Service divisions	154,749
Unobligated	3,494
Total	1,632,912

In addition, \$883,920 was appropriated to the National Gallery of Art, a bureau of the Institution but administered by a separate board of trustees; and \$432,500 was provided in the District of Columbia appropriation bill for the operation of the National Zoological Park.

Besides these direct appropriations, the Institution received funds by transfer from other Federal agencies, as follows:

From the State Department, from the appropriation, Cooperation with the American Republics, 1947, a total of \$139,589 for the following purposes: Operation of the Institute of Social Anthropology, including the issuance of publications resulting from its work; publication of a Spanish edition of *Compendium and Description of the West Indies*, by Antonio Vázquez de Espinosa; and assistance in the publication of the *Handbook of South American Indians*.

From the Navy Department, \$12,920 for scientific work in the Bikini area in connection with Operation Crossroads.

From the National Park Service, Interior Department, \$91,500 for archeological projects in connection with River Basin Surveys. Of this total, \$64,500 was originally transferred to the Park Service by the Bureau of Reclamation, and \$37,000 by the Corps of Engineers, U. S. Army.

SMITHSONIAN CENTENNIAL

In my last annual report I reviewed rather fully the features that marked the Institution's one-hundredth anniversary on August 10, 1946. These included a commemorative Smithsonian postage stamp; an illustrated publication entitled "The First Hundred Years of the Smithsonian Institution"; a convocation and reception at the Institution on October 23, 1946, to mark the occasion in a more formal manner; a public statement released to the press by President Harry S. Truman, who is ex-officio Presiding Officer of the Institution; and a Smithsonian Centennial issue of the journals, *Science* and *The Scientific Monthly*. In addition, many leading magazines and newspapers carried full accounts of the Institution's history and achievements, and this type of public notice of the Centennial continued well into the fiscal year 1947.

It has been particularly gratifying to the officials of the Institution to receive on the occasion of the Centennial so many letters of congratulation from distinguished scientists and educators in this country and abroad. It is satisfying to feel that there is a general recognition of the Institution's earnest efforts to carry out its founder's stipulation for "the increase and diffusion of knowledge among men," and such recognition tends to stimulate greater zeal in furthering James Smithson's purpose.

FINANCES

A statement on finances, dealing particularly with Smithsonian private funds, will be found in the report of the executive committee of the Board of Regents, page 162.

TRUST FUNDS' EMPLOYEES INCLUDED UNDER FEDERAL RETIREMENT SYSTEM

For many years employees of the Institution have been divided into two categories: The first, and by far the larger group, consists of civil-service employees paid from Federal appropriations; the second, now numbering some 35 employees, consists of employees paid wholly or in part from Smithsonian trust funds. The first group, of course, has been covered by the Federal Retirement System; the second group had up to 1939 no provision whatever for retirement. On July 1, 1939, the Smithsonian Retirement System was put into effect to provide retirement benefits for those employees paid from trust funds, but the number of members was so small that the system was unable to offer anything like as liberal benefits as the Federal System as amended in 1942.

During the fiscal year 1947, the Civil Service Commission took under advisement the inclusion of trust funds' employees under the Federal System, and pending a decision, the Board of Regents of the Institution at its annual meeting on January 17, 1947, passed the following resolution:

Resolved, That the Board of Regents of the Smithsonian Institution do hereby consent to the officers and members of the Smithsonian Institution paid from trust funds accepting the benefits and privileges of the Federal Retirement System, as well as assuming the obligations and duties legally applicable to them under that system as presently constituted; *Provided further*,

That the Board of Regents of the Smithsonian Institution does not consent to the application of the Federal civil-service laws, nor the Federal Classification Act of 1923, as amended, to such officers and members paid from trust funds, nor to the application of any other laws which would in any way contravene the act of Establishment of the Smithsonian Institution approved on August 10, 1846, with amendments thereto.

Resolved, That the Regents of the Smithsonian Institution, if and when officers and members of the Smithsonian Institution paid from trust funds are placed under the Federal Retirement System, approve in principle the use of the funds now held in the Smithsonian Retirement Fund for the benefit of the employees in question, to secure for said employees the maximum protection under the Federal Retirement Act to which their length of service in the Smithsonian Institution, respectively, entitles them; and that the Secretary be authorized to work out the necessary plans to carry this into effect, with the approval of the executive committee, to which is given full power to act in this matter.

A decision was reached by the Commission on May 16, and on May 22 I sent the following memorandum to the members of the Smithsonian Retirement System:

The Civil Service Commission has decided under date of May 16, 1947, that Smithsonian employees paid from trust funds of the Institution are eligible for inclusion under the Federal Retirement System. In accordance with the approval of the Board of Regents, the Smithsonian Retirement System is therefore abolished, effective at the close of business May 17, 1947, except insofar as it

affects payments to members in annuity status on that date, which payments will be continued by the Institution as provided by the Smithsonian Retirement System.

Beginning May 18, 1947, retirement deductions from the pay of the Smithsonian employees in question will be made at the rate of 5 percent (the rate of the Federal Retirement System) instead of 3.5 percent (the rate of the former Smithsonian Retirement System).

Adjustment for back time on behalf of the individual members of the Smithsonian Retirement System will be determined with the approval of the executive committee, as provided by resolution adopted by the Board of Regents on January 17, 1947.

On June 30, the last day of the fiscal year 1947, I submitted to the executive committee of the Board of Regents a detailed recommendation regarding the conversion to the Federal Retirement System, so that final action on adjustment for previous service will be deferred until the next fiscal year. However, all employees of the Institution are now on the same footing as to retirement benefits, thus remedying a situation of long standing.

VISITORS

An increase of 237,784 visitors to the Smithsonian buildings was recorded over the previous year, the totals being 2,353,377 for 1947 and 2,115,593 for 1946. August 1946 was the month of largest attendance, with 318,325 visitors; April 1947, the second largest with 298,724. A summary of attendance records is given in table 1:

TABLE 1.—Visitors to the Smithsonian buildings during the year ended June 30, 1947

	Smithsonian Bldg.	Arts and Industries Bldg.	Natural History Bldg.	Aircraft Bldg.	Freer Gallery of Art	Total
<i>1946</i>						
July.....	51,955	118,106	64,553	21,964	10,504	267,082
August.....	62,254	137,857	81,674	24,005	12,535	318,325
September.....	45,152	93,356	55,256	18,625	9,339	221,628
October.....	32,052	63,843	49,016	13,428	8,939	167,273
November.....	28,538	58,667	42,804	13,054	7,961	151,024
December.....	20,292	34,640	28,335	8,331	5,865	97,463
<i>1947</i>						
January.....	18,492	34,019	34,553	8,919	4,121	100,104
February.....	16,285	33,240	28,329	7,876	4,053	89,783
March.....	20,037	47,114	37,797	11,336	7,003	123,287
April.....	55,236	127,665	76,488	23,541	15,794	298,724
May.....	42,372	111,480	68,480	19,318	11,625	253,275
June.....	47,292	116,179	70,632	21,803	9,498	265,404
Total.....	439,967	976,166	1,637,917	192,100	107,237	2,353,377

¹ Not including 13,943 persons attending meetings after 4:30 p. m.

PHOTOGRAPHIC LABORATORY

In connection with the research and exploration of the Institution, there is involved a large amount of photographic work which is handled for the Institution and its branches by the Photographic Labora-

tory, located in the Arts and Industries Building of the National Museum. To show the quantity of work produced I will give a few statistics: Negatives made, 2,449; prints, 14,521; enlargements, 2,082; lantern slides, 264; cloth mounts, 174; also a smaller number of other types of work involving photographic processes.

In addition to the routine operations of the laboratory, the staff spent considerable time in assisting scientists of the Institution in obtaining photographic illustrations for their publications, as well as in aiding representatives of other governmental agencies and private individuals in their search for needed photographs.

The photographer in charge served as the Institution's representative on the photograph supplies committee, Federal Specifications Board. He attended monthly board meetings and conducted special investigations for various subcommittees of the Board. While representing the Institution at the annual convention of the Photographers' Association of America in Chicago, the photographer in charge visited the Chicago Natural History Museum in the search for improved methods of photographing art objects, silverware, and glassware.

The greatest needs of the laboratory are a complete catalog of file prints, so that the large and valuable collection of negatives would be more readily accessible to the Institution's staff as well as to the general public; certain items of modern photographic equipment; and the fitting up of a room to be devoted to color photography.

BUILDINGS AND EQUIPMENT

Repairs and alterations.—Among important projects in connection with the several buildings, the following were completed during the year:

Smithsonian Building: The metal finials on top of the northeast and southeast towers were removed and new copper finials were installed; removal of the wooden louvres on four sides of the flag tower (begun in 1946) was completed and new copper louvres were installed in their place; the rooms formerly occupied by the property clerk were dismantled and converted into additional space for the accounting office.

Arts and Industries Building: Provision was made for office rooms for the National Air Museum by partitioning off room 30, formerly occupied by the division of engineering; major alterations and repairs were made in the southwest and west south ranges to provide exhibit areas for the section of manufactures and the section of aeronautics (now the National Air Museum); a photographic dark room was constructed in the section of photography; the coin hall ceiling and walls were repaired and repainted and all exhibit cases were revarnished.

Natural History Building: All alcoves in the foyer, where all special exhibitions are held, were re-covered with monks cloth and all exposed woodwork repainted; to provide storage and working space for the coral collection, a section of the second floor at the northwest corner was remodeled, including changing partition walls, erection of a gallery, and painting of walls, ceiling, and storage cases.

Freer Gallery of Art: The photographic studio and dark room were constructed by remodeling a section of one of the existing storage rooms.

Heat, light, and power.—Electric current used during the year amounted to 1,664,710 kilowatt-hours. This figure represents an increase of 120,571 kilowatt-hours over 1946 despite the "brown-out" during the period November 23 to December 9, 1946, for the purpose of conserving coal during the miners' strike. However, this increase is not considered excessive because additional fixtures were added and other improvements were made during the year.

Steam consumption was held to the absolute minimum requirements during the year, and despite the fact that heating temperatures were reduced 5° twice each day during the period November 23 to December 9, 1946, steam consumption increased 1,502,900 pounds over 1946. This increase was due to lower outside temperatures during the heating season. Total steam consumption for the fiscal year was 54,902,700 pounds.

Ice production.—The Smithsonian ice plant produced 186.7 tons of ice at a cost of \$1.16 per ton, exclusive of labor. The plant was closed down 10 days during May 1947 for overhauling.

Fire protection.—The fire hose, couplings, nozzles, and hose racks purchased during fiscal year 1946 were received and installed in the Smithsonian Building. Plans have been made to install a central control station for valving the standpipe lines in this building during the fiscal year 1948. Inspections of apparatus were made each month, and all soda and acid extinguishers were discharged and recharged.

Respectfully submitted.

A. WETMORE, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operation of the United States National Museum for the fiscal year ended June 30, 1947.

COLLECTIONS

Nearly 757,000 specimens, about twice as many as last year, came to the Museum's collections during the year, these being divided among the various departments as follows: Anthropology, 9,445; biology, 533,098; geology, 205,549; engineering and industries, 5,239; history, 3,539. Most of the accessions were acquired as gifts from individuals or as transfers from Government departments and agencies. The complete report on the Museum, published as a separate document, includes a detailed list of the year's acquisitions, of which the more important are summarized below. Catalog entries in all departments now total 19,561,872.

Anthropology.—Archeological material came from many parts of the world, especially noteworthy being about a hundred items from Adak Island in the Aleutians; nearly 1,600 specimens from Montgomery County, Md.; a tripod bowl from a ruin near Oaxaca, Mexico; 2 earthenware bowls from the Taino site of La Caleta, Province of Trujillo, Dominican Republic; 2 Roman or Franko vessels from Speicher, Germany; and 14 stone implements and fragments from Larimer County, Colo.

In ethnology, the year's accessions included collections from the North American tribes of Alaska and the Aleutians, Eastern Woodlands, Great Plains, and the Southwest; the Indian tribes of México, Panamá, Venezuela, Colombia, Bolivia, and Brazil; the Oceanian peoples of Hawaii and New Guinea; the aboriginal tribes of Australia; the Indonesians of Java, Sumatra, and Bali; the Asiatic peoples of India and Mongolia; and the African tribes of the Belgian Congo and neighboring parts of West Africa. A collection of major importance was received as a result of the bequest of the late Princess Abigail W. Kawanakoa of Honolulu, comprising a well-documented group of masterpieces of Hawaiian handicrafts which were heirlooms of the Hawaiian royal family. A valuable collection of American historical Staffordshire china was received from an anonymous donor.

The most unusual accession in physical anthropology consisted of unpublished anthropometric and other data collected by German anthropologists in Poland during World War II, together with some of their anthropological measuring instruments. The data had been assembled for the Institut für Deutsche Ostarbeit and were transferred to the National Museum as a permanent loan by the War Department. The material includes information on 356 Ukrainians, 1,466 Poles, and 162 Huzuls, with full measurements, photographs, and personal, medical, and family histories of each subject.

Biology.—The most important mammalian accession was a series of about 600 glass slides of sectioned hairs, collected and presented by Dr. Ned Dearborn, expert on fur-bearing animals, who has made a special study of mammalian hair. The W. L. Abbott fund made possible three noteworthy avian accessions: 1,758 skins and skeletons of birds from Colombia, collected by M. A. Carriker, Jr.; 453 bird skins and 7 skeletons of Panama birds, collected by Dr. A. Wetmore and W. M. Perrygo; and 556 birds from India, collected by Sálím Ali. Also from India came 1,500 bird skins resulting from the Smithsonian Institution-Yale University Expedition, containing many forms new to the Museum. Foremost among the year's herpetological acquisitions were 25 rare Brazilian frogs, 112 reptiles from Bikini, and 5 series of reptiles and amphibians from Colombia, Bolivia, Haiti, and Guatemala.

Two large and outstanding collections of fishes were received as a result of the Smithsonian's participation in two federally sponsored projects—about 38,700 fishes (representing over 300 species) taken during Operation Crossroads at Bikini and in the northern Marshall Islands by Dr. Leonard P. Schultz and Capt. Earl S. Herald, and 28,000 Guatemalan fishes obtained by Associate Curator Robert R. Miller in continuation of the survey of the fishery resources of Guatemala begun last year under the auspices of the Guatemalan Government, the United States Fish and Wildlife Service, and the Smithsonian Institution. The Pacific material, because of its extent, will make it possible for the first time to make a study of anatomical variations among the various island fish populations, while the Guatemalan material is one of the best collections of fresh-water fishes ever made in Central America. In addition, smaller but important lots of fishes came from Argentina, Baja California, Cuba, and the Tropical Pacific.

About 12,000 insects, in three accessions, came to the Museum as a direct result of the war: 1,500 from the Philippines and New Guinea, collected by Carl O. Mohr; 4,500 from the Philippines, collected by Dr. Frank M. Young; and 6,000 mosquitoes, resulting from the investigations in the South Pacific by the Naval Medical Research Unit No. 2. Another large insect accession was the gift of the H. G. Bar-

ber collection of Hemiptera, amounting to 35,000 specimens and including some types and paratypes. Other important entomological material included over 2,500 insects from Colombia, collected by Curator E. A. Chapin in 1946; about 2,000 insects collected by Dr. J. P. E. Morrison as a part of Operation Crossroads biological investigations; nearly 400 aquatic insects collected in Guatemala by Dr. Robert R. Miller; about 16,000 specimens of Mexican and Canal Zone insects collected by N. L. H. Krauss; and 65,000 specimens transferred from the United States Department of Agriculture.

A great variety of marine invertebrates was received but the largest accession in this division was the gift of the Horton H. Hobbs private collection of crayfishes. Comprising about 11,000 specimens, it is by far the most important series of these crustaceans ever collected from the southeastern United States. The Operation Crossroads investigations yielded over 8,000 miscellaneous marine invertebrates from the Marshall Islands. A desirable personal collection of nearly 3,000 worms and crustaceans from various localities came as a gift from the collector, Leslie Hubricht. The type collection of Foraminifera was increased by 706 slides, bringing the total in this collection to 10,640 slides. In the division of mollusks the largest and most important of the year's accessions comprised about 200,000 specimens collected by Associate Curator Morrison in the biological reconnaissance of the Marshall Islands in connection with Operation Crossroads. The Naval Medical Research Unit No. 2 turned over to the Museum 25,000 specimens, mainly of land and fresh-water mollusks, from China, the Philippines, and the Marianas. Dr. A. R. Loeblich, Jr., now a member of the staff of the department of geology, donated 1,200 marine shells from Okinawa.

Accessions in the division of plants (including diatoms) aggregated nearly 44,000 specimens, from many parts of the world. About 4,800 plants came as a result of Associate Curator Morton's botanical field work in St. Vincent, Lesser Antilles, a region heretofore but scantily represented in the National Herbarium. In transfers from the United States Department of Agriculture, the Museum received 5,500 grasses from Brazil, collected by Jason R. Swallen, and 1,500 specimens of bamboos, collected by Dr. F. A. McClure. Several other large lots came from South America, the West Indies, Japan and Formosa, the South Pacific, and several parts of North America.

Geology.—The department of geology received about $4\frac{1}{2}$ times as many specimens as last year, this increase being due largely to a great influx of invertebrate fossils to the number of about 200,000.

Additions in mineralogy and petrology were somewhat fewer than usual, though gifts, exchanges, and purchases brought some fine new minerals, gems, and meteorites to the collections. Twenty-one meteor-

ites not previously represented in the Museum were received during the year. Forty-four mineral specimens were purchased through the Canfield fund.

Collecting trips by Dr. G. A. Cooper and Dr. A. R. Loeblich, Jr., yielded over 36,000 Paleozoic fossils for the invertebrate collections. Several gifts received were important in helping to fill the study series in invertebrate paleontology and paleobotany. Among these were 85 Mississippian ammonoids from Arkansas, numerous Lower Permian specimens from New Mexico, extensive collections of Middle Devonian invertebrates, excellent Eocene echinoids from Florida, 120 blocks of Cambrian and Ordovician limestone with choice silicified brachiopods from the Arbuckle Mountains, 275 Tertiary fossils from Florida, extensive sets of Paleozoic and Cretaceous invertebrates, including many micro-organisms and bryozoans, 375 specimens of unusual Cambrian and Lower Ordovician fossils from Quebec, 4,000 Upper Devonian fossils from New Mexico, and 2,000 Paleozoic invertebrates from Virginia, and a similar collection from Georgia.

Resumption of field work following the war also brought increased material to the division of vertebrate paleontology. Outstanding was the discovery in one block in the Bridger Eocene beds of the skulls and portions of the skeletons of two unusually large rodents of the genus *Paramys*. Among other rarities in the season's finds were jaws and skeletal parts of the artiodactyl *Helohyus*, about five examples of the minute insectivore *Nyctitherium*, and remains of the marsupial *Peratherium*. Other additions to the Bridger collections made by Dr. C. L. Gazin were skulls of the large six-horned mammal *Uintatherium*, the titanotheres *Palaeosyops*, and the rhinoceros *Hyrachyus*. Among the materials transferred from the United States Geological Survey was a nearly complete skull and jaws of a Triassic reptile, a phytosaur, from the Petrified Forest of Arizona.

Engineering and industries.—In the division of engineering an outstanding accession was the motor tricycle designed and built at Pittsburgh in 1897 by Louis S. Clarke, automobile pioneer, and claimed to be the first Autocar. Several ship models received enhanced the watercraft collection. Two accessions in the field of microscopy are of unusual interest: The curious ruling machine with which Charles Fasoldt, in the mid-nineteenth century, produced the ruled slides and gratings prized over all others by many well-known microscopists; and a group of microscopes and accessories collected by the late Dr. Richard Halsted Ward, first president of the American Microscopical Society, and his son, the late Dr. Henry Baldwin Ward, parasitologist.

A historically important accession in the division of crafts and industries was one of the two original rubber masticators developed by Thomas Hancock in England prior to 1830. The machine was in

continual use in rubber manufacture in England for more than 75 years. To the section of textiles there came many outstanding examples of new fabrics and fabric application and an exhibit showing the manufacture and uses of nylon. In wood technology 964 exotic woods were received as an exchange from the Forest Products Research Laboratory of Great Britain, most of them heretofore unrepresented in the section's collections. In addition, 182 wood specimens were received from the New York State College of Forestry and 561 photomicrographic prints of sections of Japanese woods from the War Department.

In the division of graphic arts the most notable accession of the year was a microengraving machine capable of engraving the Lord's Prayer 781,250 times within a square-inch area. This miraculous contrivance was constructed by the Rev. J. C. Crawford after the original machine invented by W. Peters in London in 1852. Outstanding pieces of motion-picture equipment received included a 60-mm. camera invented in 1893 by George Demeny of France and manufactured by the Gaumont Co. around 1896; a 16-mm. Bell & Howell gun-type camera adopted and used by the Navy to photograph the earth from a German V-2 rocket fired at the Army Ordnance Proving Grounds, White Sands, N. Mex., October 10, 1946; and a 1911 Pathé Frères 35-mm. hand-operated projector. Sixty glass negatives taken in the late nineteenth century by the photographer Robert Stead and 143 lantern slides taken by the photographer Titus B. Snoddy, Sr., came as gifts to the Museum. Five more etched copper plates were added to the Charles W. Dahlgreen group for printing under the Dahlgreen fund.

Several interesting and desirable additions were received for the division of medicine and public health, the most valuable one of the year being a series of specially prepared transparencies illustrating the subject of hospitalization. These were made and contributed by the American Hospital Association as a memorial to the late Dr. S. S. Goldwater (1873-1942). Historically important is a "Grosse Flamme" X-ray machine with tube and tube stand, one of the earliest American-made machines of its kind.

A number of desiderata found their way to the aeronautical collections, the most outstanding in point of historic importance being the collection of parts remaining of original gliders devised by John J. Montgomery between 1905 and 1911. From the standpoint of relationship to air warfare and particularly the devastating effect of bombing as practiced in World War II, the Norden bombsight used in directing the first atomic bomb dropped over Japan constitutes an important accession. A series of 82 interesting scale-model World War II airplanes were transferred from the Navy Department. Three other aircraft models received were of an XFL-1 Bell "Airabonita"

made by Leroy McCallum, an F-6-F Grumman "Hellcat" made in the Navy Department, and a rotary-winged craft named "Hiller-copter" made by Stanley Hiller, Jr.

History.—Several interesting additions made to the costumes collection include a waistcoat and knee breeches of mauve satin and a dark blue and white silk waistcoat worn by Simon Serre in Cette, France, as a page boy about the mid-eighteenth century; a child's dress and pair of shoes of about 1850; a black silk dress of about 1860, a trousseau of 1875; and a white satin dress worn in the White House by Mrs. John Quincy Adams during her husband's administration as President. Added to the military collections were early nineteenth-century chapeaux, epaulets, sash, coat, and trousers; a United States Marine Corps officer's sword of the early part of the present century; and two Chinese scrolls that had been presented to Gen. James H. Doolittle in commemoration of the American air raid on Tokyo in 1942. From the White House there was transferred a historic passenger elevator installed in 1902. The numismatic collection was increased by 30 specimens of 1946 United States bronze, nickel, and silver coins and by 400 pieces of German paper currency of the World War I period. About 3,000 stamps were added to the philatelic collection, about 1,300 more than last year. Of particular interest was a sheet of 50 3-cent Smithsonian Centennial commemoratives, formally presented to the Institution by the Post Office Department at a special ceremony on August 10, 1946.

EXPLORATION AND FIELD WORK

One of the most encouraging phases of the Museum's work during the year was an opportunity to resume field work, interrupted by the war.

Under a grant from Ernest N. May, it was possible for the curator of ethnology, Herbert W. Krieger, to renew investigations of fifteenth-century historic Indian village sites and some of the early Spanish settlements in the West Indies. This Caribbean program developed from an earlier Antillean project sponsored by the late Dr. W. L. Abbott which began in 1928 and was terminated in 1938. Dr. Abbott's interest was aroused by the earlier discoveries there by W. H. Gabb in 1869-71 of kitchen middens containing deposits of animal bones and aboriginal pottery fragments. While engaged in the development of the ensuing Smithsonian project for the excavation of these cave middens and of other former Indian village sites in the Greater Antilles and in the Bahamas, the need became apparent to the curator for a chronological culture-trait analysis and for a more complete orientation as to the location of historic Indian village sites, and also for a study of Spanish settlements associated with the early colonial

period of the area. The cooperation of scientists and the governments of the Bahama Islands, Haiti, Cuba, and the Dominican Republic was readily obtained in the carrying out of the details of the project. From January 16 to May 5, 1947, Mr. Krieger visited and made test excavations at Indian village sites referred to by Christopher Columbus in the journal of his first voyage of discovery. Mr. Krieger also examined the probable site of the first Spanish settlement, that of the sailors of the wrecked *Santa María* at La Navidad near the town of Cap Haïtien on the north coast of Haiti. He later revisited La Isabela, the first planned Spanish colony in the Western Hemisphere. The ruins of the stone buildings of the town are still visible although most of the stone walls of the large warehouse, church, fort, and other buildings have been removed to the city of Puerto Plata, where they have been used in the construction of modern buildings.

During the first 2 weeks of August 1946 Mr. Krieger attended, as a delegate of the Smithsonian Institution, the First International Conference of Archeologists of the Caribbean, which was convened under the auspices of the Government of the Republic of Honduras. The plenary sessions of the conference were held at the capital city of Tegucigalpa, but as the work progressed meetings were held most pleasantly under towering trees at the ruins of the eighth-century Maya city of Copan, on the stone seats of the south section of the Court of the Hieroglyphic Stairway. Ample facilities were provided by the Honduras Government for the attending delegates, 60 in number, representing 14 American Republics and 36 educational and scientific institutions. Visits were made by airplane to widely separated sites where the prolific remains of Maya and other aboriginal cultures are still visible in the form of pyramids, mounds, and ruins of abandoned Indian villages in the upland valleys of western Honduras.

The late Dr. Aleš Hrdlička, formerly curator of physical anthropology, had planned to visit Guatemala in December of 1943 to take measurements and observations on the Highland Maya, but he died in September of that year. Dr. T. Dale Stewart finally undertook this work during the first 3 months of 1947 under a grant from the Department of State and in cooperation with scientists from Guatemala and the Carnegie Institution of Washington. In addition to studying the living, Dr. Stewart examined also the available prehistoric skeletal remains, especially those recovered from the archeological sites known as San Agustín Acasaguastlán, Kaminaljuyú, and Zaculeu.

The main objective of Dr. Stewart's trip was to obtain information about the living Highland Maya which would enable him to make comparisons with the Lowland Maya of Yucatán. These two groups, although rather widely separated geographically and exhibiting dif-

ferences in material culture, nevertheless belong to the same linguistic stock. This linguistic stock, moreover, is remarkably homogeneous. Since language is fairly resistant to change (more so than material culture), considerable interest attaches to the question whether this linguistic homogeneity reflects a similar status in physical type.

Dr. Stewart undertook the collection of data that would supplement those already available and at the same time allow their fuller interpretation. Since in Guatemala the municipio, being endogamous, is the basic unit for ethnic study, he restricted his study to two municipios within the Cakchiquel linguistic subgroup. First at Sololá in the Department of Sololá, then later at Patzún in the Department of Chimaltenango, he secured comparable series of males—82 to 72, respectively—and at Patzún, a series of 35 females. Altogether this is the largest series from one highland linguistic group thus far studied. In addition to the routine anthropometric measurements, observations, and photographs, the records obtained this season include blood group (A, B; M, N), taste sensitivity to phenyl thiocarbamide, palm and finger prints, and hair samples. In view of the success of this first season, it is hoped that the experience thus gained can be utilized for the extension of these observations elsewhere. It is important, for example, to learn also to what extent in the highlands the barrier of language is an aid in the formation of physical types. Furthermore, if the records are made by one observer, they will be more uniform and less subject to multiple personal biases.

Upon his return from Guatemala Dr. Stewart was detailed to stop over in Mexico City in order to examine the recently recovered skeleton of Tepexpan man. This important skeleton, found in what is considered by paleontologists as a *Pleistocene stratum*, may represent one of the most complete skeletons dating from this early period in North America. Subsequent to his visit the entire skeleton has been brought to the United States National Museum by Señor Javier Romero, who is to work with Dr. Stewart in the restoration and reconstruction of the skeletal parts. At the close of the fiscal year some progress has been made in the restoration of the facial bones.

Dr. Waldo R. Wedel, associate curator of archeology, was on detail to the River Basin Surveys and in charge of the Missouri River Basin Survey from July 8 to October 18, 1946. He left Washington May 20, 1947, to resume this work. Joseph R. Caldwell, scientific aid, likewise was detailed to the River Basin Surveys from November 12, 1946, to April 1, 1947. (See appendix 5 for details.)

Members of the staff of the department of biology participated in several important expeditions and a number of smaller field trips, all of which returned valuable material to the collections. From other expeditions in which the Museum personnel did not take part but which were financed by the Smithsonian Institution or private con-

tributors, many additional specimens were received. Foremost among the expeditions was Operation Crossroads under the auspices of the United States Navy to the northern Marshall Islands and Bikini. Taking part in the biological investigations of this operation and representing the Smithsonian Institution were Drs. Leonard P. Schultz and J. P. E. Morrison, curator of fishes and associate curator of mollusks, respectively, and Capt. Earl S. Herald, whose detail the Navy requested from the Army to relieve Dr. Schultz. Dr. Schultz returned to Washington by plane on July 22, having left Washington on the preceding February 13. Captain Herald returned to Washington in mid-September. As ichthyologists, Dr. Schultz and Captain Herald were especially concerned with the relative abundance of fishes on the reefs and in the tidal zone before and after dropping the experimental atomic bombs. In connection with the investigation they preserved over 38,000 specimens for study and for the national collections. Dr. Morrison, who left Washington on February 20 and returned August 25, gave his attention to both the vertebrate and invertebrate animal life of the area, excepting the fish. He obtained specimens and data concerning the arboreal, terrestrial, and intertidal animal communities and populations. Particularly complete was the series of birds frequenting Bikini and the collections of mollusks of this and other of the Marshall Islands group. On June 28, 1947, 2 days before the close of the fiscal year, Drs. Schultz and Morrison accompanied by Frederick M. Bayer, assistant curator of marine invertebrates, started on a return trip to Bikini for a resurvey of the faunal elements of the area with which they were particularly concerned.

In continuation of the survey of the fishery resources of Guatemala begun last year under the joint auspices of the Guatemalan Government, the United States Fish and Wildlife Service, and the Smithsonian Institution, Dr. Robert R. Miller, associate curator of fishes, spent some 10 weeks, March 7 to May 17, in Guatemala. Extensive series of fish and associated animal life were obtained, the fish collected to form the basis of an account of the fishes of that country.

On March 15, 1947, C. V. Morton, associate curator of plants, left for a 12-week trip to St. Vincent, British West Indies, on a botanical survey of that island with funds generously provided by Ernest May, of Wilmington, Del. Although St. Vincent has an interesting flora, it has been relatively neglected by collectors. Owing to the mountainous terrain, there is still a great deal of untouched forested land which provided ideal conditions for plant collecting. Mr. Morton obtained 4,800 specimens on which he plans to base a checklist of the flowering plants and ferns of the island.

The W. L. Abbott fund financed three different field parties during the past year: M. A. Carriker, Jr., continuing field work in Colombia, working for half the year in areas complementary to those already

The last 2 weeks of the season were spent in going over Lower Eocene beds in the Wind River Basin of central Wyoming and in examining and making a collection from an isolated occurrence of Duchesne River, Upper Eocene, beds in the northern part of the Wind River Basin.

Associate Curator D. H. Dunkle, accompanied by F. L. Pearce, left for field work near Lamy, N. Mex., prior to the close of this fiscal year. There, assisted by G. F. Sternberg, they began quarry operations at a Triassic locality for an exhibition slab of ancient amphibian skulls and other skeletal parts belonging to the genus *Buettneria*. This has now been quarried out and is ready for shipment to the Museum. If the season permits, they expect to examine other localities and formations of still greater age for fossil fish and primitive tetrapods in the general region of east-central New Mexico, with the hope of building up a more representative collection of these forms for our study collection.

The 5-month sojourn in Japan of Curator W. F. Foshag and Associate Curator E. P. Henderson may well be considered a field trip, since, whenever time permitted, studies were made on mineralogical subjects, local universities were visited, and arrangements for exchange of material were concluded.

PUBLICATIONS

Fourteen publications were issued during the year: One Annual Report, three Bulletins, two Contributions from the National Herbarium, and eight Proceedings papers. A list of these is given in the complete report on Smithsonian publications, appendix 12.

The distribution of volumes and separates to libraries and other institutions and to individuals aggregated 34,952 copies.

MEETINGS AND SPECIAL EXHIBITS

The Smithsonian continued to make available the auditorium and lecture room of the Natural History Building to educational, scientific, welfare, and governmental organizations and groups for meetings and lectures. During the year 275 groups availed themselves of this opportunity. The foyer and adjacent space in the Natural History Building were in constant use during the year for a series of 15 special exhibits sponsored by various groups, including the Smithsonian Centennial exhibit, which ran from August 10 to September 27, 1946. In addition, 23 special exhibits were held by the division of graphic arts—12 of etchings, lithographs, and other prints by various artists, and 11 of photographs.

CHANGES IN ORGANIZATION

Through a reorganization in the department of engineering and industries, a new unit under the division of crafts and industries—the section of manufactures—was established effective September 16, 1946. The section of aeronautics was changed to a division on January 6, 1947, and at the same time the division of medicine and public health was made an independent division reporting to the head curator of the department.

Respectfully submitted.

ALEXANDER WETMORE, *Director.*

The SECRETARY,
Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit, on behalf of the Board of Trustees of the National Gallery of Art, the tenth annual report of the Board, covering its operations for the fiscal year ended June 30, 1947. This report is made pursuant to the provisions of section 5 (d) of Public Resolution No. 14, Seventy-fifth Congress, first session, approved March 24, 1937 (50 Stat. 51).

ORGANIZATION AND STAFF

During the fiscal year ended June 30, 1947, the Board consisted of the Chief Justice of the United States, the Secretary of State, the Secretary of the Treasury, the Secretary of the Smithsonian Institution, ex officio, and five general trustees, Samuel H. Kress, Ferdinand Lamot Belin, Duncan Phillips, Chester Dale, and Paul Mellon.

At its annual meeting held on May 6, 1947, the Board reelected Samuel H. Kress as President, and Ferdinand Lamot Belin as Vice President, to serve for the ensuing year. The executive officers continuing in office during the year were:

Huntington Cairns, Secretary-Treasurer.

David E. Finley, Director.

Harry A. McBride, Administrator.

Huntington Cairns, General Counsel.

John Walker, Chief Curator.

Macgill James, Assistant Director.

Donald D. Shepard continued to serve during the year as Adviser to the Board.

On July 1, 1946, Lamont Moore was appointed Curator in charge of education and resumed his duties in the Gallery after an absence of 3 years. During that time he served in the Army of the United States in the European Theater and as Assistant Secretary to the American Commission for the Protection and Salvage of Artistic and Historic Monuments in War Areas.

The three standing committees of the Board, provided for in the bylaws, as constituted at the annual meeting of the Board, held May 6, 1947, were:

EXECUTIVE COMMITTEE

Chief Justice of the United States, ex officio, Fred M. Vinson, Chairman.

Samuel H. Kress, Vice Chairman.

Ferdinand Lamot Belin.

Secretary of the Smithsonian Institution, Dr. Alexander Wetmore.
Paul Mellon.

FINANCE COMMITTEE

Secretary of the Treasury, ex officio, John W. Snyder, Chairman.
Samuel H. Kress, Vice Chairman.
Ferdinand Lamot Belin.
Paul Mellon.
Chester Dale.

ACQUISITIONS COMMITTEE

Samuel H. Kress, Chairman.
Ferdinand Lamot Belin, Vice Chairman.
Duncan Phillips.
Chester Dale.
David E. Finley, ex officio.

The permanent Government positions on the Gallery staff are filled from registers of the United States Civil Service Commission, or with its approval. On June 30, 1947, the permanent Government staff of the Gallery numbered 305 employees, as compared with 298 employees on June 30, 1946.

Throughout the year a high standard of operation and maintenance of the Gallery building and grounds, and protection of the Gallery's collections of works of art, has been sustained.

APPROPRIATIONS

For salaries and expenses for the upkeep and operation of the National Gallery of Art, the protection and care of works of art acquired by the Board of Trustees, and all administrative expenses incident thereto pursuant to the provisions of section 4 (a) of *Public Resolution No. 14, Seventy-fifth Congress, first session*, approved March 24, 1937 (50 Stat. 51), the Congress appropriated for the fiscal year ended June 30, 1947, the sum of \$883,920. This amount included the regular appropriation of \$772,490, a supplemental appropriation of \$101,000 primarily to meet the Gallery's obligations under the Federal Employees Pay Act of 1946, and an additional appropriation of \$10,430 to make up other deficiencies in the 1947 appropriation caused mainly by the higher salaries paid returning veterans over war service incumbents, in-grade promotions, and reallocations of positions by the Civil Service Commission in 1946 and 1947.

From these appropriations the following expenditures and encumbrances were incurred:

Personal services.....	\$771, 508. 54
Printing and binding.....	3, 990. 72
Supplies, equipment, etc.....	108, 382. 23
Unencumbered balance.....	29.51
Total	883,920. 00

In addition to the above-mentioned appropriations, the Gallery received the sum of \$21,600 from the Department of State to cover expenses during the fiscal year of the Inter-American Office of the Gallery, for the promotion of art activities between the United States and the Latin-American Republics.

ATTENDANCE

During the fiscal year 1947, there were 1,448,038 visitors to the Gallery building, an average daily attendance of 3,989. This attendance figure shows a decline as compared with last year, when the total number of visitors was 1,947,668. The decrease is undoubtedly due to the fact that during the first 6 months of the fiscal year there were fewer men and women from the armed services in the city and normal tourist traffic had not yet been resumed. Attendance during the last 3 months of the year has risen nearly to the 1946 level, visits of groups of school children being unusually numerous.

The Sunday evening openings, featuring concerts in the Gallery's East Garden Court without admission charge, have continued to be exceedingly popular throughout the year.

CARE AND MAINTENANCE OF THE BUILDING

It was necessary during the year to overhaul completely two of the large refrigeration machines, and this was successfully accomplished by the Gallery staff.

Considerable improvement has been made in the care of the grounds, including the extension of the irrigation system, and the Gallery staff is now growing a large portion of the smaller plants used for the decoration of the two garden courts.

The staff also produced all the special exhibition cases and several pedestals for the exhibition of Indigenous Art of the Americas (Bliss Collection), as well as the special lighting effects required for this exhibition.

INSTALLATION OF ADDITIONAL AIR-CONDITIONING EQUIPMENT

As stated in the annual report for the fiscal year 1946, the gradual opening of additional spaces in the Gallery building and the construction of six new galleries made it necessary to augment the air-conditioning equipment. This was made possible by funds donated for the purpose, and the installation of a fourth refrigeration machine is now in the final stage of completion. It was anticipated that this contract would be completed during the fiscal year 1946, but owing to various difficulties the date of completion was necessarily delayed. It is now expected that the installation should be completed and all equipment ready for operation by November 1947.

PUBLICATIONS

The publishing program of the National Gallery of Art, under the direction of the Custodians of the Publications Fund, has continued its expansion. During the fiscal year the third edition of *Masterpieces of Painting from the National Gallery of Art*, by Huntington Cairns and John Walker, was published. Arrangements also were made for the publication of an English edition. The Gallery has initiated a series of National Gallery of Art handbooks, two of which were issued during the year. These are: *How to Look at Works of Art: The Search for Line*, by Lois A. Bingham, and *Chinese Porcelains of the Widener Collection*, by Erwin O. Christensen. Also issued during the year was a small volume of color reproductions, entitled "*Favorite Paintings from the National Gallery of Art*," with accompanying texts prepared by the Curatorial and Educational Departments.

Various articles by members of the Gallery staff were published during the year. An article on Hobbes' Theory of Law, by Huntington Cairns, appeared in the 1946 issue of *Seminar*, and one on Leibniz's Theory of Law in the *Harvard Law Review* for December 1946. A lecture by Mr. Cairns, delivered at Harvard University on May 3, 1947, as part of a 3-day Symposium on Music Criticism, and entitled "*The Future of Musical Patronage in America*," will be published by Harvard University Press in book form. Mr. Cairns also contributed an article, "*Philosophy as Jurisprudence*," to *Essays in Honor of Roscoe Pound*, published by Oxford University Press. A comprehensive article on the National Gallery, its collections, installations, and history, prepared by J. B. Eggen, was issued at the close of 1946 as volume 57-58 of the *International Museum Journal*, Mousseion, Paris, France.

An article on *American Painters and British Critics*, by John Walker, was published in the *Gazette des Beaux-Arts*, and a series of 12 brief articles on American paintings in the Tate Exhibition, also by Mr. Walker, appeared in *The Ladies' Home Journal*. Charles Seymour, Jr., published an article on Thirteenth-Century Art, and another in collaboration with Hanns Swarzenski on *A Madonna of Humility and Quercia's Early Style*, both appearing in the *Gazette des Beaux-Arts*. James W. Lane contributed to *Art in America*, *The College Art Journal*, *The Catholic World*, and other publications. Members of the curatorial staff under Mr. Seymour's direction also edited the handbook of the Bliss Collection of Pre-Columbian Art, entitled "*Indigenous Art of the Americas*," the text for which was supplied by Samuel Lothrop.

Books by members of the staff in preparation or in press at the end of the fiscal year included *The Limits of Art*, by Mr. Cairns, an extensive compilation of selections of poetry and prose that have been held to be

the greatest of their kind in critical literature from Aristotle to recent times. A fully illustrated volume on the Gallery's sculpture, designed as a companion volume to Masterpieces of Painting, by Messrs. Cairns and Walker, is being prepared by Mr. Seymour for publication next year under the title "Sculpture in the National Gallery of Art." A book by Elizabeth Mongan on the Gallery's print collection will appear in 1949. A thesis on Jan Mandijn, by Charles M. Richards, will also be published. A work entitled "Three Centuries of American Painting" has been prepared by James W. Lane. A comprehensive work on the Index of American Design, tentatively entitled "Made in America," is being compiled by Mr. Christensen for publication in the near future. Another book by Mr. Christensen scheduled to appear jointly in the United States and England is entitled "Popular Art in the United States." A picture book on the paintings and sculpture in the Widener Collection is now on the press, and five handbooks on the Widener Collection of Decorative Arts have been prepared by Mr. Christensen.

Work on the revision and amplification of the Gallery's original preliminary catalog, published in 1941, has continued. For the revised catalog of paintings, notes have been prepared on more than three-fourths of the new paintings not previously cataloged. The sculpture catalog, being prepared by Mr. Seymour, is also moving rapidly to completion.

Other forthcoming publications by members of the Gallery staff include an article by Huntington Cairns on Robert Briffault and the Rehabilitation of the Matriarchal Theory for An Introduction to the History of Sociology, to be published by the University of Chicago Press, and also an article on The Future of Musical Patronage, to appear in the Atlantic Monthly. A second series of short articles by Mr. Walker, on paintings in the Chester Dale Collection, will appear in The Ladies' Home Journal. An article on Houdon by Mr. Seymour is scheduled for publication in the Gazette des Beaux-Arts, and an article on American Folk Art as Revealed in the Index of American Design, by Mr. Christensen, will be published in Art in America.

Miss Mongan has been made an editor of the Graphic Art section of a new edition of the Encyclopaedia Britannica. Mr. Christensen has reassembled and organized unbound copies of the Widener tapestry catalog into portfolios for sale in the Information Rooms and distribution to colleges.

The Publications Fund has continued to supply color reproductions of fine quality but moderately priced, and it is rather interesting to note that in one item—postcards of works of art—nearly 3,000,000 copies have been sold since the Gallery was opened in 1941.

Publishers of large collotype reproductions of paintings in the National Gallery have added 14 new titles to their lists during the fiscal year 1947, and the Publications Fund is now able to offer a total of 52 of these large reproductions to the public.

CUSTODY OF GERMAN SILVER

Under date of February 21, 1947, the Secretary of War requested the National Gallery of Art to provide space and safe storage for the Hohenzollern silver service, following a ruling by the War Department with the concurrence of the Treasury Department that the silverware is the property of the United States. On April 11, 1947, the Gallery received from the War Department 44 sealed cases, weighing approximately 7 tons, said to contain silverware and glassware, and placed the cases in a storage room for indefinite custody and storage.

ACQUISITIONS

GIFTS OF PAINTINGS AND SCULPTURE

On August 8, 1946, the Board of Trustees accepted the following group of 19 French paintings from Samuel H. Kress and the Samuel H. Kress Foundation:

<i>Artist</i>	<i>Title</i>
Boucher, Francois.....	Allegory of Painting.
Boucher, Francois.....	Allegory of Music.
Boucher, Francois.....	Madame Bergeret.
Drouais, Francois-Hubert.....	Group Portrait.
Fragonard, Jean-Honore.....	A Game of Horse and Rider.
Fragonard, Jean-Honore.....	A Game of Hot Cockles.
Fragonard, Jean-Honore.....	The Visit to the Nursery.
Greuze, Jean-Baptiste.....	Monsieur de la Live de Jully.
Watteau, Antoine.....	Italian Comedians.
Chardin, Jean-Baptiste Simeon.....	Portrait of an Old Woman.
Le Nain, Louis.....	Landscape with Peasants.
Lorrain, Claude (Gellee, Claude).....	The Herdsman.
Nattier, Jean-Marc.....	Madame de Caumartin as Hebe.
Poussin, Nicolas.....	The Baptism of Christ.
Rigaud, Hyacinthe.....	President Hebert.
Vigee-Lebrun, Elisabeth.....	Marquise de Laborde.
Watteau, Antoine.....	"Sylvia" (Jeanne-Rose Guyonne Benozzi).
Ingres, Jean-Auguste-Dominique.....	Madame Moltessier.
Pater, Jean-Baptiste-Joseph.....	Fete Champetre.

The Board of Trustees on November 25, 1946, accepted from Samuel H. Kress and the Samuel H. Kress Foundation the painting, "The Laocoon," by El Greco, and the portrait of Monsignor Diomede Falconio, by Thomas Eakins, from Stephen C. Clark. On January 7, 1947, the Board of Trustees accepted from an anonymous donor a

portrait of Gen. Dwight D. Eisenhower, by Thomas E. Stephens, to be held for a National Portrait Gallery. On May 6, 1947, the Board of Trustees accepted two paintings, "Love as Conqueror" and "Love as Folly," by Jean-Honore Fragonard, from Miss Jean Simpson; a portrait of Captain Charles Stewart, by Thomas Sully, from Mrs. Maude Monell Vetlesen; and also resolved to accept a bust of John Muir, by Edwin Keith Harkness, from Mrs. Ione Bellamy Harkness, to be held for a National Portrait Gallery. The Board of Trustees also on May 6, 1947, recorded their prior acceptance from Mrs. Frederica R. Giles of a painting entitled "Ships in the Scheldt Estuary," by Abraham Storck.

GIFTS OF DECORATIVE ARTS

On November 25, 1946, the Board of Trustees accepted from Mrs. Lessing J. Rosenwald a miniature painting, on ivory, of Maria Miles Heyward, by Edward Greene Malbone, which was accompanied by a pin with a painting of an eye of Maria Miles Heyward, by Malbone.

GIFTS OF PRINTS AND DRAWINGS

The Board of Trustees, on August 8, 1946, accepted a collection of 273 prints and drawings bequeathed by Mrs. Addie Burr Clark, a further gift of 255 prints and drawings from Lessing J. Rosenwald, and 3 prints, *En Ballade*, by Constantine Guys, *Head and Bust of a Woman*, by Sir Joshua Reynolds, and *Le Stryge*, by Meryon, from Myron A. Hofer. On November 25, 1946, the Board of Trustees accepted from Myron A. Hofer a print, *Morgue*, by Meryon. On January 7, 1947, the Board of Trustees accepted a further gift of 399 prints and drawings from Lessing J. Rosenwald, and an engraved portrait of Charles I of England, by Vorsterman, from Willis Ruffner. The Board of Trustees on May 6, 1947, accepted from an anonymous donor a mezzotint entitled "The Mill," by Charles Turner, after Rembrandt.

GIFTS TO THE INDEX OF AMERICAN DESIGN

The Board of Trustees, on May 6, 1947, accepted from Albert Lewin 40 water-color drawings by Perkins Harnly for the Index of American Design.

EXCHANGE OF WORKS OF ART

The Board of Trustees during the fiscal year 1947 accepted the offer of Lessing J. Rosenwald to exchange an engraving by Schongauer entitled "Crucifixion," two lithographs by Whistler entitled "Study" and "Lady Haden," and an engraving by Brosamer entitled "Christ on Cross," for superior impressions of like engravings and lithographs now included in the Rosenwald Collection at the National Gallery of Art.

LOAN OF WORKS OF ART TO THE GALLERY

During the fiscal year 1947 the following works of art were received on loan:

<i>Partioulars</i>	<i>Artist</i>
From Mrs. Ailsa M. Bruce, New York, N. Y.:	
2 tapestries.	
The Raising of Tabitha.....	Tournai, c. 1460.
The Conversion of the Centurion Cornelius....	Tournai, c. 1460.
From George Matthew Adams, New York, N. Y.:	
124 drawings and etchings.	
From Charles B. Harding, Laura Harding, and Catharine H. Tailer, New York, N. Y.:	
Portrait of Victor Guye.....	Goya.
From Mrs. Huttleston Rogers, New York, N. Y.:	
The Tricycle.....	Monet.
Roses.....	Renoir.
The Artist and the Widow.....	Forain.
Chemin dans le Brouillard.....	Monet.
Le Tribunal de Pontoise.....	Pissarro.
Le Jour d'Hiver.....	Sisley.
Roses in a Chinese Vase and Sculpture by Maillol.....	Vuillard.
Maternity.....	Gauguin.

LOANED WORKS OF ART RETURNED

During the year the following works of art loaned to the Gallery were returned to the lenders:

<i>Partioulars</i>	<i>Artist</i>
To the French Government:	
The entire collection of French paintings on loan, with the exception of Mlle. DuBourg (Mme. Fantin-Latour).....	Degas.
To the Belgian Government:	
12 of the 14 paintings on loan, leaving 2 pic- tures belonging to M. Stuyck del Bruyere.	
To the J. H. Whittemore Co., Naugatuck, Conn.:	
Avant la Course.....	Degas.
To Col. Axel H. Oxholm, Washington, D. C.:	
Martha Washington.....	Attributed to Ralph E. Earl.
To Mrs. Huttleston Rogers, New York, N. Y.:	
Roses.....	Renoir.
The Artist and the Widow.....	Forain.
Chemin dans le Brouillard.....	Monet.
Le Tribunal de Pontoise.....	Pissarro.
Le Jour d'Hiver.....	Sisley.
Roses in a Chinese Vase and Sculpture by Maillol.....	Vuillard.
Maternity.....	Gauguin.

LOAN OF WORKS OF ART BY THE GALLERY

During the fiscal year 1947, the Gallery loaned the following works of art for exhibition purposes:

<i>Particulars</i>	<i>Artist</i>
To The Art Institute of Chicago, Chicago, Ill.:	
3 rugs.	
To M. Knoedler & Co., New York, N. Y.:	
Ralph Waldo Emerson-----	Thomas Sully.
To the National Collection of Fine Arts, Washington, D. C.:	
4 miniatures:	
Louis de Bourbon, Prince de Conde-----	Petitot.
Henri Jules, Duc d'Albert-----	Petitot.
Maria Miles Heyward-----	Malbone.
Pin with painting of an eye of Maria Miles Heyward-----	Malbone.
To the Wildenstein Galleries, New York, N. Y.:	
Breezing Up-----	Winslow Homer.
To the Society of the Cincinnati, Washington, D. C.:	
Alexander Hamilton-----	John Trumbull.
To the J. B. Speed Memorial Museum, Louisville, Ky.:	
Henry Clay-----	John James Audubon.
Henry Laurens-----	John Singleton Copley.
Andrew Jackson-----	Ralph E. Earl.
DeWitt Clinton-----	John Wesley Jarvis.
Jane Cutler Doane-----	Samuel King.
William Rush-----	John Neagle.
General William Moultrie-----	Charles Willson Peale.
George Washington-----	Rembrandt Peale.
Mrs. George Pollock-----	Gilbert Stuart.
Governor Charles Ridgely-----	Thomas Sully.
James Monroe-----	John Vanderlyn.
Self-Portrait-----	Benjamin West.
Mary Walton Morris-----	John Wollaston.
To the Tate Gallery, London, England:	
150 examples from the Index of American Design.	
To the U. S. Department of State, Blair-Lee House, Washington, D. C.:	
Daniel Webster-----	George P. A. Healy.
To the White House, Washington, D. C.:	
Men of Progress-----	Schussele.
George Washington (porthole portrait)-----	Rembrandt Peale.
Andrew Jackson-----	Ralph E. Earl.

EXHIBITIONS

The following exhibitions were held at the National Gallery of Art during the fiscal year ended June 30, 1947:

Life of Christ as depicted in the etchings of Rembrandt. Prints from the Rosenwald Collection and an anonymous lender, from May 14 to September 8, 1946.

Audubon prints, "Birds of America." Elephant folio set by John James Audubon, from May 26 to July 28, 1946.

Music in prints. Prints from the Rosenwald Collection, from June 18 to December 8, 1946.

Made in America. One hundred and eleven water colors from the Index of American Design, from August 4 to September 15, 1946.

American etchings, woodcuts, and lithographs. Prints from the collection of the National Gallery of Art, from September 11 to October 2, 1946.

New acquisitions in the Rosenwald Collection. Additional prints and drawings acquired by Lessing J. Rosenwald, from September 22 to December 1, 1946.

Sculpture, drawings, and prints by Rodin. From the collections of Mrs. John W. Simpson and Lessing J. Rosenwald, from October 6 to December 12, 1946.

Paintings looted from Holland by the Nazis, returned through the efforts of the United States Armed Forces. Forty-six paintings circulated under the supervision of the Albright Art Gallery, Buffalo, N. Y.; scheduled for showing at various museums throughout the country; shown at National Gallery from December 7, 1946, to January 1, 1947.

Liber Studiorum, by J. M. W. Turner. Prints from the National Gallery of Art collections, from December 10, 1946, to April 27, 1947.

The Christmas Story in prints. Prints from the National Gallery of Art collections, from December 13, 1946, to February 5, 1947.

Prints and drawings by Alphonse Legros. Prints and drawings from the collection of George Matthew Adams, of New York, from January 12 to February 16, 1947.

American paintings. Portraits from the collection of the National Gallery of Art, from February 23 to March 30, 1947.

Woodcuts, lithographs, and etchings by Paul Gauguin and Edvard Munch. Prints by Gauguin lent anonymously, prints by Munch from the Rosenwald Collection, from April 6 to May 30, 1947.

Indigenous Art of the Americas. Pre-Columbian art from the collection of the Honorable Robert Woods Bliss, of Washington, D. C., from April 18, 1947, to continue for an indefinite period.

Prints and drawings by William Blake. Prints from the National Gallery of Art collections and loans, from April 29 to June 8, 1947.

Chiaroscuro woodcuts from the sixteenth through the eighteenth centuries. Lent anonymously. Opened June 8, 1947.

Prints by James Abbott McNeill Whistler. Prints from the collection of the National Gallery of Art, opened June 13, 1947.

TRAVELING EXHIBITIONS

Index of American Design. Exhibitions from this collection of water colors, drawings, etc., have been shown during the fiscal year 1947 at the following places: Lyman Allyn Museum, New London, Conn.; Seamen's Bank for Savings, New York, N. Y.; Hood College, Frederick, Md.; Dallas Museum of Fine Arts, Dallas, Tex.; Northwestern University, Evanston, Ill.; Library of Congress, Washington, D. C.; Lakeside Press Galleries, Chicago, Ill.; Philadelphia Museum of Art, Philadelphia, Pa.; Massillon Museum, Massillon, Ohio; College of Wooster, Wooster, Ohio; McMurray College for Women, Jack-

sonville, Ill.; Salt Lake City Junior League, Salt Lake City, Utah; Palette Club, Ogden, Utah; Rockford Art Association, Rockford, Ill.; Speed Memorial Museum, Louisville, Ky.; N. W. Ayer Gallery, Philadelphia, Pa.; and the American Federation of Arts, Washington, D. C., for circulation throughout the United States.

Rosenwald prints. During the fiscal year 1947 special exhibitions of prints from the Rosenwald Collection were circulated to the following places:

The Art Institute of Chicago, Chicago, Ill.:

William Hogarth collection of engravings. October to November, 1946.

Duke University, Durham, N. C.:

Daumier loan exhibition. December 1946.

Philadelphia Museum of Art, Philadelphia, Pa.:

Survey of water color. Nine water colors, four miniatures, including Blake, Fragonard, Gauguin, Rembrandt, Cameron, and McBey. February to March, 1947.

The Mint Museum of Art, Charlotte, N. C.:

Daumier loan exhibition. February 1947.

California Palace of the Legion of Honor, San Francisco, Calif.:

Nineteenth-century French exhibition of drawings by Manet, Delacroix, Daumier, Degas; from the Rosenwald and Hofer Collections. March 1947.

The University of North Carolina, Chapel Hill, N. C.:

Daumier loan exhibition. March 1947.

Detroit Institute of Arts, Detroit, Mich.:

Six centuries of prints. May to August, 1947.

Four exhibitions of Rosenwald prints were arranged and held at Alverthorpe Gallery, Jenkintown, Pa.

VARIOUS GALLERY ACTIVITIES

During the period from July 1, 1946, through June 30, 1947, a total of 52 Sunday evening concerts were given in the East Garden Court of the Gallery. The concerts were free to the public, and were attended by over 50,000 persons. During March 1947 five concerts were devoted to American composers, comprising the Gallery's Fourth American Music Festival.

A total of 4,056 copies of press releases, 130 special permits to copy paintings in the Gallery, and 107 special permits to photograph in the Gallery were issued during the year.

Of the seven 16-mm. sound prints of the film, National Gallery of Art, originally owned by the Gallery, three have been sent to foreign countries. The first gift was to the National Gallery of Victoria, Melbourne, Australia; another print was deposited with the American Embassy in Paris on indefinite loan, and later was given to the Embassy; a third print was given to the American Embassy in Lisbon, Portugal.

The film was made available to 16 institutions and individuals during the year. One of the 16-mm. prints was on loan in South Carolina for several months during the winter, in which time it was viewed by approximately 3,000 people.

INDEX OF AMERICAN DESIGN

For the period from July 1, 1946, to June 30, 1947, reproductions of Index material were used in a number of magazines, including *Fortune*, *Life*, *Antiques*, *The American Collector*, *Architectural Review*, and *Art in America*. There were 118 new users of the Index this year, and 24 people revisited the collection. The great majority of them made a special trip to Washington for the purpose of studying Index material. They included a university class in American art, designers, manufacturers, artists interested in design motifs, authors, editors, publishers, etc. A total of 1,048 photographs of Index designs were sold for use in commercial design by individuals and by firms, for hobbies, for publications, for teaching purposes, for publicity, and for reference and exhibitions. During the year 449 new slides were made of Index material for use in lectures.

INTER-AMERICAN OFFICE

During the fiscal year 1947 the Inter-American Office of the National Gallery of Art has continued to devote its efforts to the circulation of exhibitions in the other American Republics. These exhibitions, two of original works of art and six consisting of photographic panels, have been very well received in Latin America.

CURATORIAL DEPARTMENT

During the past year there were 1,510 new accessions by the Gallery as gifts, loans, or deposits, including paintings, sculpture, prints, and the decorative arts. These accessions were registered and the great majority placed on exhibition, or in the case of prints, placed on file and available to the public. A total of 161 works of art were brought to the Gallery for expert opinion, and 92 visits were made to collections of private individuals in connection with offers of gift or loan, or possible acquisitions for the Gallery. The curatorial staff made 290 written and 293 verbal replies to questions from the public requiring research. During the year 17 lectures and 3 lecture courses were given by members of the curatorial staff.

Other activities of the Curatorial Department include the following: The collections of paintings and drawings belonging to the French and the Belgian Governments were packed and dispatched to Europe during this year; the collection of American paintings assembled by

the Gallery for exhibition at the Tate Gallery in England was received, unpacked, inspected, and returned to its original owners; a collection of 46 paintings from Dutch sources was received, exhibited, and dispatched on its tour of the United States; and the Bliss Collection of Pre-Columbian Art was exhibited in a special installation arranged by the curatorial staff at the entrance of the central gallery. The cataloging and filing of photographs in the Richter Archive is now four-fifths finished.

RESTORATION AND REPAIR OF WORKS OF ART

With the authorization of the Board and the approval of the Chief Curator the necessary restoration and repair of works of art in the Gallery's collection were made by Stephen S. Pichetto, Consultant Restorer to the Gallery. All work was completed in the Restorer's studio in the Gallery.

EDUCATIONAL PROGRAM

The survey tours of the whole collection continue to be a vital part of the Educational Department's program, satisfying the demand of the many sightseers and newcomers to Washington who feel the need for a general introduction to the Gallery as a whole. More than 10,000 persons attended the General, Congressional, and Wing Tours, while over 27,000 attended the Gallery Talks and the Picture of the Week. Approximately 28,000 came to hear the lectures and other programs in the auditorium. Special appointments, tours, and conferences were arranged for 2,169 persons. The Educational Department has continued the publication of a printed monthly announcement of all the Gallery's activities. It has a circulation of 5,900 copies.

LIBRARY

A total of 1,076 books, 467 pamphlets, and 596 periodicals were given to the National Gallery of Art; 20 books were purchased and 27 periodicals were subscribed to. A total of 59 books, 119 pamphlets, and 393 bulletins were received on exchange from other institutions; 204 photographs and 80 slides were presented as gifts to the library. Outstanding among the gifts were 75 American history books, particularly useful as background material for the Index of American Design. This year, 2,054 books were borrowed and returned, 1,986 of which were borrowed from the Library of Congress. For the remaining 68, the Gallery is indebted to museum and university libraries and public libraries.

PHOTOGRAPHIC DEPARTMENT

During the year the photographic laboratory of the Gallery made 17,111 prints, 506 black-and-white slides, and 1,729 color slides, in

addition to 2,170 negatives, and 87 X-rays, infrared photographs, ultraviolet photographs, and color separation negatives.

OTHER GIFTS

During the year gifts of books on art and related material were made to the Gallery Library by Paul Mellon, David K. E. Bruce, the Victoria and Albert Museum, Chester Dale, Miss Fernande L. Herrman, and Dr. Herbert Friedmann. Gifts of money during the fiscal year 1947 were made by Paul Mellon, Mrs. Maude Monell Vetlesen, and David E. Finley. A sum of money was anonymously given with the provision that the income therefrom will be available for the acquisition of contemporary works of art by American artists, and for prizes and awards to American artists.

AUDIT OF PRIVATE FUNDS OF THE GALLERY

An audit has been made of the private funds of the Gallery for the fiscal year ended June 30, 1947, by Price, Waterhouse & Co., public accountants, and the certificate of that company on its examination of the accounting records maintained for such funds will be forwarded to the Gallery.

Respectfully submitted.

HUNTINGTON CAIRNS,
Secretary.

THE SECRETARY,
Smithsonian Institution.

APPENDIX 3

REPORT ON THE NATIONAL COLLECTION OF FINE ARTS

SIR: I have the honor to submit the following report on the activities of the National Collection of Fine Arts for the fiscal year ended June 30, 1947:

THE SMITHSONIAN ART COMMISSION

The twenty-fourth annual meeting of the Smithsonian Art Commission was held on Friday, December 6, 1946, having been postponed from its regular date, the first Tuesday in December. The members assembled at 10:30 a. m., in the Smithsonian Building to pass on the works of art which had been offered during the year. The following action was taken:

Accepted for the National Collection of Fine Arts

Oil painting, *Self Portrait*, by G. P. A. Healy (1813-94). Gift of Ruel P. Tolman.

Oil painting, *A Morning in Summer*, by Leonard Ochtman, N. A. (1854-1934). Henry Ward Ranger bequest.

Plaster bust of Charles Henry Niehaus, by Adolph Alexander Weinman, N. A. (1870-). Gift of Miss Marie J. Niehaus.

Plaster plaque of Joseph Pennell, by John Flanagan (1865-). Gift of Miss A. Margaretta Archambault.

Raku tea bowl, made by Yanagisawa Kien (1703-58). Gift of Miss Catharine McE. Ames.

Miniature, *Portrait of a Man*, by George Catlin (1796-1872). Gift of Bernard N. Burnstine:

Twenty-two miniatures and one silver medal. Gift of Mrs. Henry DuPrè Bounetheau:

Mrs. Arthur Middleton (1791-1840) (Alicia Hopton Russell), by Henry B. Bounetheau (1797-1877), after the original by Andrew Robertson, 1836.

Peter Bounetheau in Magistrate's Robes (1742-98), father of the artist, by Henry B. Bounetheau, after head of the Benbridge miniature.

Peter Bounetheau (1742-98), by Henry Benbridge (1744-1812).

Mrs. John Middleton (Mary Burroughs), by Henry B. Bounetheau, after an English artist.

Self Portrait, 1867, after picture when 50 years old, by Henry B. Bounetheau.

Mrs. Henry B. Bounetheau (1822-69) (Julia Clarkson DuPrè), by Henry B. Bounetheau.

Henry DuPrè Bounetheau, 1849 (1842-1901), by Henry B. Bounetheau.

Mme. Julia DuPrè, about 1830, mother of Mrs. Henry B. Bounetheau, by a French artist.

Henry Gourdin, of Charleston, godfather of the artist's son, by Henry B. Bounetheau.

Portrait of an Unknown Man, painted about 1838-42, by Henry B. Bounetheau.

Portrait of an Unknown Woman, painted about 1840-60, by Henry B. Bounetheau.

Portrait of an Unknown Woman, by an English artist.

Napoleon as General, by Henry B. Bounetheau, after Sully, after Appiani.

King Lear in the Storm, by Henry B. Bounetheau, after Sir Joshua Reynolds.

George Washington, by Henry B. Bounetheau, after Gilbert Stuart.

Henry B. Bounetheau's Aunt, c. 1804, by Edward Greene Malbone (1777-1807).

Portrait of an Unknown Woman, by an unknown artist.

Frances Anne Kemble (1809-93), by Henry B. Bounetheau, after Thomas Sully.

General George Washington, by Henry B. Bounetheau, after the Trumbull at Charleston, S. C.

Napoleon Bonaparte, by Henry B. Bounetheau, after Favre.

Unmasked, by Henry B. Bounetheau, after a colored engraving by W. Nicholas, after the painting by Mrs. Pierson, published in London, April 1, 1831, by J. Brookes.

Sleeping Beauty, by Henry B. Bounetheau.

Silver medal awarded to Mr. Bounetheau for the best miniatures on ivory, by The South Carolina Institute, 1849.

Accepted for the Smithsonian Institution

Bronze statue, Ecstasy, by Francisco Albert. Gift of the sculptor.

Celadon vase, made by Makuzu Kōzan. Gift of Milo E. Emmerson.

The members then met in the Regents Room, adjacent, for further proceedings of the annual meeting. The meeting was called to order by the chairman, Mr. Manship, at 11:25 a. m.

The members present were: Paul Manship, chairman; Dr. Alexander Wetmore, secretary (member, ex officio); and Robert W. Bliss, John N. Brown, George H. Edgell, David E. Finley, George H. Myers, Archibald G. Wenley, and James E. Fraser. Ruel P. Tolman, Director of the National Collection of Fine Arts, also attended.

The resignation of Louis Ayres was submitted and accepted with regret. The secretary was instructed to write Mr. Ayres expressing the appreciation of the Commission for his valuable services while a member.

The resignation of Frank J. Mather, a charter member, was submitted and accepted with regret. The secretary was instructed to invite Mr. Mather to all future meetings, and to inform him that the Commission would consider him a member emeritus.

The Commission recommended to the Board of Regents the name of William T. Aldrich to succeed Mr. Ayres, and Lloyd Goodrich to succeed Mr. Mather.

The Commission recommended the re-election of John Taylor Arms, Gifford Beal, and Gilmore D. Clarke for the usual 4-year period.

The following officers were elected for the ensuing year: Paul Manship, chairman; Robert Woods Bliss, vice chairman; and Dr. Alexander Wetmore, secretary.

The following were elected members of the executive committee for the ensuing year: David E. Finley, chairman, Robert Woods Bliss, and Gilmore D. Clarke. Paul Manship, as chairman of the Commission, and Dr. Alexander Wetmore, as secretary of the Commission, are *ex officio* members of the executive committee.

THE CATHERINE WALDEN MYER FUND

Nine miniatures, water color on ivory unless otherwise stated, were acquired from the fund established through the bequest of the late Catherine Walden Myer, as follows:

55. Portrait of an Officer, signed "Rockstuhl, fec."; from James W. Lane, Chevy Chase, Md.

56. Portrait of a Young Man, by unknown artist; from James W. Lane, Chevy Chase, Md.

57. Portrait of a Gentleman, by Henry Inman, N. A. (1801-46), water color on paper; from Mrs. Dorothy Draper Hamlen Sale, Parke-Bernet Galleries, Inc., New York City.

58. Portrait of a Gentleman, by Thomas Seir Cummings (1804-94); from Mrs. Dorothy Draper Hamlen Sale, Parke-Bernet Galleries, Inc., New York City.

59. Joseph W. Faber of Charleston, S. C., by Charles Fraser (1782-1860); from Mrs. Dorothy Draper Hamlen Sale, Parke-Bernet Galleries, Inc., New York City.

60. Alexander Rose, by John Ramage (before 1763-1802); from Mrs. Dorothy Draper Hamlen Sale, Parke-Bernet Galleries, Inc., New York City.

61. Harriet Hampton, by Charles Fraser (1782-1860); from Mrs. Dorothy Draper Hamlen Sale, Parke-Bernet Galleries, Inc., New York City.

62. Roger Brooke Taney (1777-1864), by unknown artist; from Mamie C. Faulconer, Alexandria, Va.

63. Little Girl with Doll, by John Carlin (1813-91); from Edmund Bury, Philadelphia, Pa.

LOANS ACCEPTED

Two enamel miniature portraits of Louis de Bourbon, Prince de Conde, and Henri Jules, Duc d'Albret, by Jean Petitot, the Younger (b. 1653), with frames by Gilles Legare de Chaumont (1610-c1653), and two miniatures on ivory, a Portrait of Maria Miles Heyward (Mrs. William Drayton), and her "Eye," by Edward Greene Malbone, about 1803, were lent by the National Gallery of Art, with the permission of the donor, Lessing J. Rosenwald, on March 6, 1947.

One miniature on ivory, Portrait of Robert Goodloe Harper (1765-1825), by Benjamin Trott, was lent by the family of Robert Goodloe Harper Speed, on June 27, 1947.

WITHDRAWALS BY OWNERS

Two Bohemian glass vases, lent in 1928, were withdrawn by the owner, Mrs. Robert Lee Preston, on August 2, 1946.

A collection of 22 pieces of porcelain and bronzes, lent in 1918, was withdrawn by the owner, Mrs. Geraldine L. Hitchcock, on April 3, 1947.

An oil painting, Portrait of Mrs. Stephen Decatur (Susan Wheeler), by Gilbert Stuart, and four crayon drawings on paper, by Saint Memin, of Ann Decatur Pine, Capt. James McKnight, Capt. Stephen Decatur, Sr., and Ann Pine McKnight Decatur, lent in 1943, were withdrawn by the owner, Mrs. William F. Machold, on April 15, 1947.

An oil painting, Portrait of Hon. Charles Evans Hughes, by George Burroughs Torrey, lent in 1936, and a marble bust of Hon. Charles Evans Hughes, by Bryant Baker, lent in 1943, were withdrawn by the owner, Mr. Hughes, on May 21, 1947.

Five oil paintings, Hildegard, Poinsettia, Maternity, The Old Miniature, and Study of a Young Woman, by Wallace Bryant, and a photomechanical reproduction of The Age of Innocence, lent in 1916, were withdrawn by the owner, Wallace Bryant, on June 6, 1947.

An oil painting, Portrait of Lt. Gen. Mark W. Clark, by M. Arnold Nash, lent in 1944, was withdrawn by the owner, Mrs. Mark W. Clark, on June 9, 1947.

LOANS TO OTHER MUSEUMS AND ORGANIZATIONS

An oil painting, Portrait of Stephen Decatur, by Gilbert Stuart, was lent to M. Knoedler & Co., Inc., New York City, for their Washington Irving Exhibition, October 8 to 26, 1946. (Returned October 29, 1946.)

Two oil paintings, Old Church at Giverny, and La Vachere, by Theodore Robinson, were lent to the Brooklyn Museum, Brooklyn, N. Y., to be included in an exhibition of the work of the artist, November 12, 1946, to January 5, 1947.

Two plaster busts (bronzed), George Washington, and Thomas Jefferson, by Houdon, and four vases, were lent to The White House December 3, 1946, for an indefinite period.

An oil painting, Portrait of Herbert Hoover, by Edmund C. Tarbell, was lent to The Century Association for an exhibition of portraits of members who were Presidents of the United States, January 9 to February 16, 1947. (Returned February 27, 1947.)

Two oil paintings, Entrance to the Harbor, and Groton Long Point Dunes, by Henry Ward Ranger, and four miniatures, Mrs. Putnam

Catlin and Portrait of a Man, by George Catlin, and John Trumbull Ray and Portrait of a Gentleman, by Thomas S. Cummings, were lent to the Lyman Allyn Museum, New London, Conn., to be included in their Fifteenth Anniversary Exhibition, Eighty Eminent Painters of Connecticut, March 9 to April 20, 1947. (Returned April 28, 1947.)

An oil painting, The Signing of the Treaty of Ghent, 1814, by Sir Amedee Forestier, was lent April 3, 1947, to the Committee on Un-American Activities, to be hung in its committee room for an indefinite period.

Two oil paintings, At Nature's Mirror, and Sunset, Navarro Ridge, California Coast, by Ralph Albert Blakelock, were lent to the Whitney Museum of American Art, New York City, to be included in an exhibition of paintings by the artist, April 21 through May 29, 1947. (Returned June 6, 1947.)

LOANS RETURNED

An oil painting, Fired On, by Frederic Remington, lent to The White House, June 7, 1945, was returned July 17, 1946.

THE HENRY WARD RANGER FUND

No. 69. South Dakota Evening, by Jes W. Schlaikjer, A. N. A. (1897-), previously assigned to Vassar College, Poughkeepsie, N. Y., was reassigned November 21, 1946, to San Joaquin Pioneer and Historical Society, Stockton, Calif.

The following two paintings were recalled for action on the part of the Smithsonian Art Commission, in accordance with the provision in the Ranger bequest. The Smithsonian Art Commission decided not to accept the paintings and they were returned to the museums to which they were originally assigned:

No. 7. The Shrine of the Rain Gods, by E. Irving Couse, N. A. (1866-1936), assigned to the Toledo Museum of Art, Toledo, Ohio.

No. 112. Medieval Art, by Edwin H. Blashfield, N. A. (1848-1936), assigned to the William Rockhill Nelson Gallery of Art, Kansas City, Mo.

THE NATIONAL COLLECTION OF FINE ARTS REFERENCE LIBRARY

A total of 405 publications (255 volumes and 150 pamphlets) were accessioned. This number includes 162 volumes and 41 pamphlets purchased, the priced auction catalogs of the Parke-Bernet Galleries accounting for 44 volumes and 32 pamphlets. The other accessions were publications received by exchange, gift, or transfer. The year's additions brought the total library accessions to 10,540, plus the volumes of serials formerly accessioned by the Museum Library for the National Gallery of Art, now the National Collection of Fine Arts.

SPECIAL EXHIBITIONS

June 28 through July 21, 1946.—Exhibition of 33 pieces of sculpture in bronze, marble, obsidian, wood, and stone, by Francisco Albert, of Mexico, held under the patronage of His Excellency, Señor Dr. Don. Antonio de los Monteros, the Mexican Ambassador to the United States. A catalog was privately printed.

July 3 through 21, 1946.—Exhibition of 72 Swedish wartime cartoons, sponsored by the American Scandinavian Foundation and the Sverige-Amerika Stiftelsen.

August 10 through September 25, 1946.—Smithsonian Centennial Exhibition. The National Collection of Fine Arts endeavored to honor those who had contributed to its collections, with examples of their gifts. About 50 specimens, covering 100 years, were shown.

October 3 through November 3, 1946.—An oil painting, Portrait of President Harry S. Truman, by John Slavin, of Richmond, Va., was shown in Gallery 2.

October 9 through 29, 1946.—The Fifty-sixth Annual Exhibition of the Society of Washington Artists, consisting of 103 specimens of paintings and sculpture.

November 6 through 29, 1946.—The Ninth Metropolitan State Art Contest, held under the auspices of the District of Columbia Chapter, American Artist's Professional League, assisted by the Entre Nous Club, consisting of 299 specimens of paintings, sculpture, prints, ceramics, and metalcraft.

December 12, 1946, through January 12, 1947.—The Forty-fifth Annual Exhibition of Miniatures by The Pennsylvania Society of Miniature Painters, consisting of 73 miniatures. Reprint of catalog used in Philadelphia.

March 7 through 30, 1947.—The Fifty-first Annual Exhibition of the Washington Water Color Club, consisting of 258 paintings and prints. A catalog was privately printed.

March 7 through 30, 1947.—The Fourteenth Annual Exhibition of The Miniature Painters, Sculptors and Gravers Society of Washington, D. C., consisting of 144 examples. A catalog was privately printed.

April 10 through 30, 1947.—Exhibition of 18 paintings, 4 pieces of sculpture, and photographs, by Hugh Almaraz, of Bolivia, was held under the patronage of His Excellency, the Ambassador of Bolivia and Señora de Martinez Vargas, and the Pan American Union. A catalog was printed by the Pan American Union.

June 4 through 29, 1947.—Exhibition of 29 Hawaiian Flower Panels in pastel, by Maurice Kidjel, was held under the patronage of the Delegate to Congress from Hawaii and Mrs. Joseph R. Farrington. A catalog was privately printed.

The writer, who for some years had been Acting Director, was appointed Director of the National Collection of Fine Arts on July 28, 1946.

Respectfully submitted.

R. P. TOLMAN, *Director.*

DR. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the twenty-seventh annual report on the Freer Gallery of Art for the year ended June 30, 1947.

THE COLLECTIONS

Additions to the collections by purchase were as follows:

BRONZE

- 46.18. Chinese (Ordos), Han dynasty (207 B. C.-A. D. 220). Hemispherical bowl with slightly everted lip; brown patina with areas of malachite and earthy encrustation; welded to one side is a flat horizontal handle on which stands the figure of a mule cast in the round. 0.106 x 0.182 x 0.128.
- 46.31. Chinese, Shang dynasty (1766-1122 B. C.). Ceremonial vessel of the type *ting*, light grayish-green patina with some encrustation; areas of malachite, azurite, and cuprite inside; decorated with casting in intaglio and relief; inscription of three characters. (Illustrated.) 0.354 x 0.282.
- 47.1. Chinese, 4th-3d century B. C. Folding bronze tripodal stand in three parts; decorated with gold and silver inlay. 0.574 (over all, folded).

GLASS

- 46.29. Chinese, T'ang dynasty (A. D. 618-906). Oblate bowl with broad base smaller mouth, thickened lip, and deeply concave base; thick green glass, surface ground on outside except for small transparent area in center of base; inside roughened and iridescent with deterioration; rust stain on base. 0.080 x 0.147.

GOLD

- 46.20- Chinese, T'ang dynasty (A. D. 618-906). Pair of Apsarases modeled in
- 46.21. the round in flying position with flowing robes; scarves and jeweled streamers in filigree work around bodies; crowns and floral necklaces; extended hands hold lotus flowers; ears pierced for earrings; each on an intricate filigree cloud pattern support. 0.037 x 0.088 x 0.027; 0.037 x 0.081 x 0.024.
- 46.22. Chinese, Six dynasties period (A. D. 285-589). Pair of plaques, each a thin sheet of gold with a winged horse in repoussé relief; vine patterns in background and double border of V pattern; fragments of plaster adhering to reverse side of each. 0.075 x 0.120 x 0.019; 0.075 x 0.120 x 0.016.

JADE

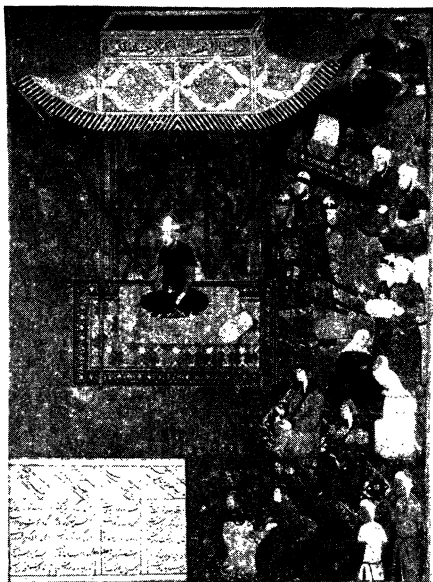
- 47.10. Chinese, 5th-3d century B. C. Cylindrical covered cup of Kotan nephrite; supported on three small feet; annular handle on one side; decoration carved in relief and intaglio; three small coiled dragons on cover. (Illustrated.) 0.170 x 0.098.

MANUSCRIPT

- 46.12. Persian, A. D. 1556-1565. *Haft Awrang* ("Seven Thrones"), the seven *mathnawi* poems of Jāmi; book of 303 folios plus 1 added folio; 28 miniature paintings in gold and color; illuminated headpieces, tailpieces, and space fillers; margins of various colors with bird and flower patterns in red and gold; repairs on some pages; lacquered binding 19th century. 0.342 x 0.232 (page size).
- 47.2. Armenian, A. D. 10th century. Page from a Gospel manuscript on parchment; canon tables on both sides; brown-black writing and decorations in red, yellow, and purple; torn and stained on edges. 0.328 x 0.246.
- 47.3. Armenian, A. D. 10th century. Page from a Gospel manuscript on parchment; on reverse: canon table; on obverse: the four evangelists standing in arches; brown-black writing and decorations in red, yellow, and purple; torn and stained on edges. 0.334 x 0.251.
- 47.4. Armenian, A. D. 10th century. Page from a Gospel manuscript on parchment; canon tables on both sides; brown-black writing and decoration in red, yellow, and purple; torn and stained on edges. 0.329 x 0.248.
- 47.6. Persian, A. D. 1557. Leaf from *Yūsuf u-Zulaikhā* by Jāmi; Persian text in small *nasta'liq* script; manuscript leaf inlaid in larger leaf of red-brown paper with border designs in gold; *recto*: horses in rock landscape; *verso*: floral scrolls with feline heads devouring antelopes; wormholes and small tears along two edges. 0.251 x 0.248.
- 47.7. Persian, A. D. 1557. Leaf from *Yūsuf u-Zulaikhā* by Jāmi; Persian text in small *nasta'liq* script; manuscript leaf inlaid in larger leaf of grayish-brown paper with border designs in gold; *recto*: floral scrolls and arabesques; *verso*: lions, foxes, and birds in landscape; wormholes. 0.252 x 0.149.

PAINTING

- 46.13. Persian, A. D. middle 16th century. Winter scene: Sūfi and courtier conversing at a shrine; color; three lines of *nasta'liq* script in upper left corner; set in an old album mount with floral designs and writing in red *nasta'liq* script. 0.328 x 0.226.
- 46.14. Persian, A. D. 1341, Mongol (Īl-Khān) period, Īnjū school. Leaf from a manuscript of *Mu'nis al-Ahrār fī Daqā'iq al-Ash'ār*: The Moon and Fish; 12 different kinds of birds in two registers; text in black *nashī* script; paper torn and colors rubbed in places; old repairs and modern margin. 0.195 x 0.134.
- 46.16. Persian, A. D. middle 14th century, Mongol (Īl-Khān) period, Īnjū school. Leaf from a *Shāhnāmah*: Arzū, the jeweler's daughter plays before Bah-rām Gūr; colors and gold; paint on three faces rubbed off; text in black *nashī* script; red rulings; marginal additions in *nasta'liq*. 0.290 x 0.209.
- 46.17. Indian, Akbar period (A. D. 1556-1605), Mughal. Lion hunt in a mountainous landscape; colors and gold; cut-out passages in *nasta'liq* script around painting; on reverse: four lines of Persian poetry in *nasta'liq* script; slightly torn; bits of paint chipped off. 0.186 x 0.106.
- 46.26. Persian, Tīmūrid period (A. D. ca. 1425-1450), Samarquand school, Ulugh Beg with ladies of his harem and retainers; colors and gold; six lines of Persian poetry in *nasta'liq* script in lower left corner; cuts and breaks in paper. (Illustrated.) 0.317 x 0.241.



46.26



46.30

RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART



47.10



46.31

RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART

- 46.27. Indian, Rājput period (A. D. 17th century), Rājasthānī, probably Jaipur school. Woman holding a *vinā* and flower under a tree with a deer, attracted by the music, in front of her; drawing in black on yellowish paper; on reverse: small drawing of bust of a woman in black and gold; small stains, tears, and some flaking. 0.166 x 0.113.
- 46.28 Indian, Mughal period (A. D. ca. 1619), school of Jahāngīr. Durbar scene of Jahāngīr; colors and gold; mounted on an album leaf; two inscriptions and identification notes; slight flaking. 0.169 x 0.123.
- 47.5. Arabic (Mesopotamia), A. D. 1224. Baghdad school. Illustration from an Arabic manuscript of the *Materia Medica* of Dioscorides; the Greek physician Erasistratos lying on a low bench with an assistant standing in front of him; opaque colors and gold; text on both sides in *naskhi* script; a few wormholes and tears. 0.322 x 0.248.

PAINTING AND MANUSCRIPT

- 46.15. Persian, A. D. 16th-17th century. Composite leaf consisting of a drawing of Dancing Sūfis by Ustād Muḥammādī of Herāt, a painting of A Cluster of Primroses by Murād, a page of prose in *nasta'liq* script, and a page of poetry in *nasta'liq* by Shāh Mahmūd; old album mounting with floral decoration in gold. 0.450 x 0.303.

POTTERY

- 46.24. Chinese, Ch'ing dynasty, Yung-ch'eng period (A. D. 1723-1736). Small bottle-shaped vase with tall neck and flaring lip; white porcelain covered with pale opaque blue-gray glaze called "claire de lune"; brown dressing on raw footrim; four-character mark in underglaze blue on base. 0.101 x 0.070.
- 46.25. Chinese, Yüan dynasty (A. D. 1279-1368), Lung-ch'üan. Vase with octagonal body, spreading foot, swelling body, and short tapering neck; grayish-white porcelain covered with thick opaque gray-green crackled glaze inset with 24 panels of reddish-brown biscuit showing human figures and floral patterns molded in relief. 0.275 x 0.175.
- 46.30. Egyptian, Fātimid period (A. D. 11th-12th century). Bowl on low foot rim; soft, fine-grained reddish clay covered with white tin glaze; decorated, inside: a dancing girl in yellow gold luster; outside: irregular circles and markings in reddish luster now partly rubbed off; repairs, five missing sherds replaced by painted plaster. (Illustrated.) 0.067 x 0.261.
- 47.8. Mesopotamian, A. D. 12th century, Rakka. Bowl with wide everted rim and low foot; coarse whitish clay covered with transparent green glaze; decorations under glaze painted in black on white slip showing a heron; repairs, two pieces of rim missing. 0.076 x 0.266.
- 47.9. Persian, Mongol period (about A. D. 1300), Sultanabad. Deep bowl with wide horizontal rim flange and foot rim; grayish medium-grained clay covered with clear transparent glaze over decoration in black outline and brown slip showing a running gazelle; lower body and foot unglazed; two small repairs on rim flange. 0.148 x 0.270.

SILVER

- 46.19. Chinese, Han dynasty (207 B. C.-A. D. 220). Plaque of solid, low-grade silver; rough and tarnished; obverse shows a leaping wolflike dog cast in relief; reverse is rough and pitted with bits of earth and malachite in some cavities. 0.099 x 0.157 x 0.013.

The work of the staff members has been devoted to the study of new accessions, of objects submitted for purchase, and to general research work within the collections of Chinese, Japanese, Arabic, Persian, and Indian materials. The preparation of materials for publication has continued. Reports, oral or written, were made upon 3,679 objects and 1,511 reproductions of objects submitted for examination; and 353 Oriental language inscriptions were translated.

REPAIRS TO THE COLLECTIONS

A total of 27 objects were remounted or repaired as follows:

Chinese calligraphy remounted.....	1
Chinese paintings remounted.....	7
Japanese paintings remounted.....	12
East Christian painting remounted.....	1
Persian miniature remounted.....	1
Greek manuscript pages repaired.....	2
Indian painting repaired.....	1
Japanese painting repaired.....	1
Persian painting repaired.....	1

CHANGES IN EXHIBITIONS

Eight hundred forty-four changes in exhibitions were made as follows:

American arts:	
Etchings.....	15
Lithographs.....	15
Byzantine arts:	
Gold.....	24
Rock crystal.....	3
Bactrian arts: Metalwork.....	4
Chinese arts:	
Bamboo wood carving.....	6
Bronze.....	101
Gold.....	11
Iron and gold.....	2
Jade.....	49
Lacquer.....	3
Painting.....	124
Pottery.....	230
Silver.....	2
Stone sculpture.....	4
Textile.....	2
Christian arts:	
Armenian manuscripts.....	25
Armenian manuscript pages.....	8
Coptic manuscript pages.....	6
Greek manuscripts.....	10
Greek manuscript pages.....	18
Greek painting.....	13

Indian arts:	
Bronze.....	1
Manuscript pages.....	2
Paintings.....	101
Stone sculpture.....	3
Japanese arts: Painting.....	6
Korean arts: Pottery.....	23
Persian arts:	
Gold.....	2
Metalwork.....	14
Syrian arts:	
Brass.....	5
Glass.....	13

In connection with the Centennial celebration of the Smithsonian Institution a special exhibition showing representative examples of Chinese art from the Neolithic age to the eighteenth century was assembled in Gallery XIII from the material in the collections. A special Gallery Book accompanied this exhibition.

In connection with the Symposium on Byzantine Studies held at the Dumbarton Oaks Research Library and Collection a special exhibition of late classical and early Christian art was assembled in Gallery VI from materials in the collections.

STUDY COLLECTIONS

A notable addition to the study collections of the Smithsonian Institution was the material given by Dr. Ernst Herzfeld, of Princeton, N. J. This gift, known as the Herzfeld Archive, was made to the Smithsonian Institution with proviso that it be deposited in, and held under the direction of, the Freer Gallery of Art, but not to be considered a part of the Freer Collection. Dr. Herzfeld's letter of transmittal to Dr. Wetmore was dated April 24, 1946, and the material reached the Gallery on June 6; but the time required to unpack the cases and make a preliminary check of the contents prevented its inclusion in the annual report dated July 1, 1946.

The material was collected by Dr. Herzfeld between the years 1903 and 1936 in the course of archeological expeditions to the Near East which included excavations at Samarra, Sistan, Pasargadae, and Persepolis. While a detailed catalog has yet to be completed, the following brief list suggests the scope and nature of the Archive:

1. 80 wooden boxes containing 50 negatives each. Catalog of the negatives. 16 files of blueprints.
2. Several hundred large drawings, water colors, plans and maps of Oriental buildings, sculpture, objects of art, etc. A number of squeezes of inscriptions.
3. 45 sketchbooks of original surveys made in the field. A number of box files with notes, texts of inscriptions, inventories, dummies for publications, etc.

4. 95 objects including pottery and metalwork of no special material value, but of some scientific interest.

It is the donor's wish that these materials be used for study and publication by members of the Institution staff and other qualified scholars, and that the objects be available for exhibition in the Institution at the discretion of the Director of the Freer Gallery of Art.

ATTENDANCE

The Gallery was open to the public from 9 to 4:30 every day except Christmas Day. The total number of visitors to come in the main entrance was 107,237. The weekday total was 80,031, and the Sunday total was 27,206. The average weekday attendance was 256, the average Sunday attendance, 523. The highest monthly attendance was in April with 15,794 visitors; the lowest, in February with 4,053 visitors.

There were 1,915 visitors to the main office during the year; the purposes of their visits were as follows:

For general information.....	1, 559
To see staff members.....	96
To read in the library.....	250
To make sketches and tracings from library books.....	9
To see building and installations.....	18
To make photographs in Court and sketches in the exhibition galleries.....	27
To examine, borrow, or purchase photographs and slides.....	389
To submit objects for examination.....	471
To see objects in storage:	
Washington Manuscripts.....	49
Far Eastern paintings and textiles.....	74
Near Eastern paintings and manuscripts.....	28
Tibetan paintings.....	5
Indian paintings and manuscripts.....	9
American paintings.....	28
American pottery.....	3
Whistler prints.....	19
Oriental pottery, jade, bronze, lacquer, and bamboo.....	83
Gold treasure and Byzantine objects.....	15
All sculpture.....	10
Syrian and other glass.....	4
	327

DOCENT SERVICE, LECTURES, MEETINGS

By request, 10 groups met in the exhibition galleries for instruction by staff members. Total attendance was 183.

On invitation, the following lectures were given outside the Gallery by staff members:

1947

- Jan. 29----- Mr. Pope read a paper on A Chinese Lacquer Statue in the Nepalese Style (45.4) before the Far Eastern Section of the College Art Association at the Metropolitan Museum of Art, New York. Attendance: 100.
- Mar. 10----- Dr. Ettinghausen lectured on Basic Facts about Oriental Rugs at the Women's Community Club, Kensington, Md. Attendance: 121.
- Mar. 17----- Dr. Ettinghausen lectured on Persian Miniature Painting at the Foxcroft School, Middleburg, Va. Attendance: 115.
- Mar. 25----- Dr. Ettinghausen lectured on Islamic Art: New Approaches in Research at the Princeton University Bicentennial Conference on Near Eastern Culture and Society, Princeton, N. J. Attendance: 65.
- Apr. 10----- Mr. Pope lectured on The Freer Gallery of Art and its Collections at the American Association of University Women, Washington, D. C. Attendance: 30.

The Auditorium was used for meetings as follows:

1946

- Oct. 9----- Bureau of Economics, U. S. Department of Agriculture. Attendance: 250.
- Oct. 10----- Bureau of Economics, U. S. Department of Agriculture. Attendance: 275.
- Oct. 11----- Bureau of Economics, U. S. Department of Agriculture. Attendance: 260.
- Nov. 20----- Office of the Attorney General, Conference on the Control of Juvenile Delinquency. Attendance: 63.
- Nov. 21----- Office of the Attorney General, Conference on the Control of Juvenile Delinquency. Attendance: 50.
- Dec. 3----- Dr. John L. Keddy, Assistant Secretary, Smithsonian Institution. Attendance: 28.

1947

- Apr. 15----- American Oriental Society, Annual Meeting. Attendance: 106.
- Apr. 16----- American Oriental Society, Annual Meeting. Attendance: 83.
- Apr. 17----- American Oriental Society, Annual Meeting. Attendance: 46.

Members of the staff traveled outside of Washington for professional purposes as follows:

1946

- Sept. 30-Oct. 23----- Mr. Pope in Chicago, Kansas City, Minneapolis, Ann Arbor, Boston, Cambridge, and New York to examine objects belonging to museums, private collections, and dealers.
- Nov. 4-13----- Mr. Wenley in Chicago, Kansas City, Minneapolis, and Ann Arbor to examine objects belonging to museums, private collections, and dealers.

1947

- Jan. 28-Feb. 9----- Dr. Ettinghausen in New York and Boston to examine objects belonging to museums and dealers.
- Mar. 17-21----- Mr. Wenley in New York to examine objects belonging to dealers.
- Mar. 24-28----- Dr. Ettinghausen attended Near Eastern Conference of the University Bicentennial Celebration at Princeton University.
- Mar. 31-Apr. 3----- Mr. Wenley attended the Conference on Far Eastern Art and Culture at the Bicentennial Celebration of Princeton University where he served as Chairman of the Conference on Chinese Painting.
- Mar. 31-Apr. 3----- Mr. Pope attended the Conference on Far Eastern Art and Culture at Princeton.
- Apr. 3----- Mr. Acker attended the Conference on Far Eastern Art and Culture at Princeton.
- Apr. 21----- Dr. Ettinghausen in New York to examine objects belonging to dealers.
- Apr. 22-23----- Dr. Ettinghausen in Princeton, N. J., to attend conference on Research in Fine Arts.
- Apr. 24----- Dr. Ettinghausen in Baltimore to attend opening of exhibition of Byzantine Art at Baltimore Museum.
- May 14----- Dr. Ettinghausen at Walters Art Gallery, Baltimore, to examine objects in the collection.
- May 23----- Mr. Pope in Philadelphia to examine objects in the Philadelphia Museum of Art.
- June 9-13----- Mrs. Usilton, Librarian, attended annual convention of Special Libraries Association, Chicago, Ill.
- June 19-20----- Mr. Pope at Fogg Museum of Art, Cambridge, Mass., to study bronze forgeries and examine objects in the collection.
- June 29-July 4----- Mrs. Usilton attended annual convention of American Library Association, San Francisco, Calif.

John A. Pope, Associate in Research, was appointed Assistant Director, July 1, 1946.

Respectfully submitted.

A. G. WENLEY, *Director.*

Dr. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1947, conducted in accordance with the Act of Congress of June 27, 1944, which provides "* * *" for continuing ethnological researches among the American Indians and the natives of Hawaii and the excavation and preservation of archeologic remains. * * *"

SYSTEMATIC RESEARCHES

Dr. M. W. Stirling, Chief of the Bureau, spent the greater part of the fiscal year in Washington, attending to administrative duties and completing for publication reports on archeological field work in southern Mexico. Two papers were completed entitled "An Archeological Reconnaissance of the State of Tabasco, Mexico," and "Piedra Parada, a Chiapas Highland Site." Considerable progress was also made on a paper entitled "Additional Stone Monuments of Southern Mexico."

Several lectures were given during the year on anthropological subjects. In April 1947 Dr. Stirling went to Houston, Tex., as representative of the Smithsonian Institution at the Inauguration of Dr. Wm. Vermillion Houston as President of Rice Institute.

Dr. Frank H. H. Roberts, Jr., Associate Chief of the Bureau and Director of the River Basin Surveys, devoted the major part of his time during the fiscal year to directing the program of the River Basin Surveys. The latter is a cooperative project between the Smithsonian Institution, the National Park Service, the Bureau of Reclamation, and the Corps of Engineers, United States Army. Its purpose is the recovery of such archeological and paleontological information and materials as will be lost through the construction of dams and the creation of large reservoirs in many of the river valleys of the United States.

In directing the survey work Dr. Roberts recruited personnel, arranged for supplies and equipment, established cooperation with local institutions in various parts of the country, prepared over-all plans for a Nation-wide archeological program, wrote progress reports for the cooperating agencies, and aided in the preparation of preliminary reports on the results of surveys in various reservoir

areas. He went to Atlanta, Ga., July 23-25, 1946, to confer with representatives of the National Park Service and engineers in the office of the Division Engineer for the South Atlantic Division, Corps of Engineers, about the problems in that area. He went to Lincoln, Nebr., September 24 to October 4, to meet the incoming field parties from the Missouri Basin. At that time he received reports on the explorations, discussed plans for future investigations, and assisted in making arrangements for carrying on the work at the field headquarters during the fall and winter months. While at Lincoln he made two trips to Omaha to confer with officials of the National Park Service, Region 2, and engineers from the office of the Division Engineer, Missouri River Division, Corps of Engineers. From December 26 to 31, he was in Chicago, Ill., to take part in a symposium on river valley archeology in which there were representatives from the National Park Service, the American Anthropological Association, the Society for American Archeology, the Committee for the Recovery of Archeological Remains, and several universities. Dr. Roberts' report on the activities of the River Basin Surveys appears in subsequent pages.

During the course of the year Dr. Roberts wrote several book reviews for anthropological journals, annotated four books for the United States Quarterly Book List, prepared a number of popular articles on the work of the River Basin Surveys, and served as a consultant on manuscripts on anthropology and archeology for several encyclopedias.

Dr. Roberts was the General Department Representative on the Efficiency Rating Board of Review for the Smithsonian Institution. In this connection he attended the Civil Service Commission Institute of Efficiency Rating Boards of Review. He represented the Smithsonian Institution at a meeting held in Washington, D. C., April 15, 1947, for the purpose of organizing a National Council for Historic Sites and Buildings.

From July 1, 1946, to June 30, 1947, Dr. Roberts served as a member of the executive committee of the Division of Anthropology and Psychology, National Research Council.

During the absences of the Chief, Dr. Roberts was Acting Chief of the Bureau.

The beginning of the fiscal year found Dr. John P. Harrington, ethnologist, at Searchlight, Nev., from which point he traveled with Murl Emery to a point above Cottonwood Island in one of the wildest portions of the Colorado River where, according to Indian tradition, is the house of Matavilya, principal deity of the lower Colorado region. The house of Matavilya was discovered to be a natural formation consisting of a butte about 200 feet high on the western side of the river, and opposite this butte another, perhaps 500 feet in height, on the

eastern side of the river. These two buttes are interpreted by the ancient Indians of the region as being what remains of the doorposts of the house of Matavilya, and Indian tradition has evidently attached itself to this place for many generations, probably for many centuries.

The interesting myth was obtained which recounts the destruction of the house at the time of the cremation of Matavilya. Considerable time was spent in checking with surviving ancient Indians in regard to the discovery of this important site, Dr. Harrington going as far as Tehachapi, Calif., for this purpose.

On November 6, 1946, Dr. Harrington returned to Washington, D. C., and the entire remainder of the fiscal year was spent in sorting over and preparing various articles for publication.

The first of these undertakings was the preparation of an article on the State Names of Mexico. This paper covers not only the state and territory names of Mexico, but also the country names of Central America and South America. Several of the etymologies are new, notably that of the name of the Mexican State of Yucatan, which is here seen to be derived perhaps from a hypothetical form Yucahtan.

The next item completed was an article on the Tewa language of New Mexico. A paper on the Province Names of Canada was next finished. Compilation for this work had long been in progress, part of it done in Canada.

An extensive paper on the Aleutian language was next written, embodying the results of previous field work in Alaska. Another paper was prepared consisting of a detailed ethnogeographic description of the projecting rocks and islands off the coast of California.

A manuscript was completed with the title "Quirix is the Native Name of San Felipe Pueblo." This paper sets forth the unique thesis that Bandelier is wrong in assuming that Quirix, which gives its name to the Keresan linguistic stock, is Bernalillo, or any site in the vicinity of Bernalillo, but that the recorded form is a Spanish spelling of the Indian name of San Felipe. The Tewa of the Castañeda account of the Coronado Expedition would then be Isleta, and Isleta is still called Tewa in Keresan.

A number of short papers were also written, the titles being as follows:

The Name Yucatan.

The Name Colorado.

The Three Earliest Mentions of the Turquoise Mines of New Mexico.

The Name Chuckwalla.

Rita, a Short-Cut for Saying Rito.

De Alarcón has the Name of Zunyi Salt Lake.

Olivella River, the Old Name of Santa Fe Creek.

Trail Holder.

H'aak'o, Original Keresan Name of Acoma.

Dr. Henry B. Collins, ethnologist, continued his investigations in Eskimo anthropology. During the winter he completed the numbering and cataloging of his collection of some 7,000 archeological specimens excavated at Cape Prince of Wales and other prehistoric Eskimo village sites around Bering Strait.

At the February meeting of the Board of Governors of the Arctic Institute of North America, Dr. Collins was elected vice chairman of the Institute. His article, *The Origin and Antiquity of the Eskimo*, tracing the Old World affiliations of the Eskimo culture and race type, will appear as one of the chapters of a general book on the Arctic to be published by the Arctic Institute.

In May Dr. Collins was appointed Chairman of the Directing Committee for the Arctic Bibliography and Roster, two separate projects which the Arctic Institute of North America is carrying out under contract for the Office of Naval Research of the Navy Department. In these projects the Arctic Institute is receiving active cooperation and assistance from the Library of Congress and the National Research Council. Officials of the latter organizations, and representatives of the Navy, Army, and Board of Governors of the Arctic Institute comprise the directing committee, which serves as a policy and advisory body with the responsibility of organizing and supervising the work on the two projects. The bibliography project will be conducted by four experienced bibliographers, with clerical assistants, working in the principal libraries in the United States and Canada. It will have as its objective the compilation of an annotated, fully indexed bibliography covering the descriptive, geographical, and other scientific literature on the Arctic from the earliest historical writings to those of the present time. It is estimated that the bibliography project will require at least 3 years for completion. The Roster of Arctic Specialists, a 2-year project, is to be conducted by a staff of three workers, headed by a former official of the National Roster of Scientific and Specialized Personnel. The roster will be patterned after the National Roster and the World Roster of Area and Language Specialists compiled by the Ethnogeographic Board during the war. Its purpose will be to assemble a comprehensive record of the experience and specialized knowledge of scientists, explorers, writers, and Arctic residents who possess first-hand information of value concerning the Arctic and sub-Arctic regions.

Dr. Collins wrote the article *Anthropology* for the 1947 *Encyclopaedia Britannica Book of the Year*. He also served as anthropological consultant for the *Encyclopedia Arctica*, which is being edited by Dr. Vilhjalmur Stefansson for the Navy Department. In this capacity he organized the anthropological sections of the *Encyclopedia* and contributed several articles on archeological subjects.

In June Dr. Collins left Washington for Martha's Vineyard, Mass., to conduct a 6 weeks' archeological survey of the island.

Returning to a study of the social organization and ceremonial life of the Seneca Nation commenced before the war, Dr. William N. Fenton, ethnologist, established field quarters on the Allegany Reservation between July 1 and September 18, when he returned to Washington. Observations made 10 years ago were repeated at meetings of two orders of the Medicine Society, and observing the Green Corn Festival for the fifth time afforded information on social and cultural change. At the behest of one of the chiefs, Dr. Fenton recorded from Fannie Stevens, matron of the Heron clan, several hundred personal names belonging to the eight Seneca clans. Recordings made in 1945 for a forthcoming album of Seneca music were played repeatedly to the singers and interpreters to assure accuracy of texts. With a possible documentary film in mind, 700 feet of 16-mm. Kodachrome moving pictures were taken of various activities in the Coldspring community. An additional week of field work from October 7 to 12 permitted verifying some of the personal names in genealogies taken in 1933.

Cultural affinities between the northern Iroquoians and their southern cousins, the Cherokee of the Great Smoky Mountains, have occupied the attention of Bureau ethnologists since Mooney's time. At the invitation of Lester M. Hargrett, of Washington, the bibliographer of Indian Laws, Dr. Fenton motored to Cherokee, N. C., in early December. We owe a brief and intensive introduction to Cherokee ethnology to Will West Long, who was 17 when James Mooney came to Cherokee and whose name is associated with the work of every field ethnologist who ventured into Big Cove settlement from 1887 until March 14, 1947, when Will passed away.

Dr. Fenton obtained information for contrasting the Boogah Dance of the Cherokee with masked performances of the Iroquois False-face Society, and some additional details were collected on the Eagle Dance, a variant of the calumet ritual, which reached the Iroquois during the eighteenth century by one documented line of diffusion from the Catawba and Cherokee of the Southeast. When recordings of Cherokee and Seneca Eagle Dance songs are compared, it will develop that they are derived from a common source. Photographs were made of the Cherokee mask-making process, and some portraits of Mr. Long in characteristic Eagle Dance postures. A report of these findings has been prepared for publication.

Two collections of Americana seen on this trip deserve mention. The MacGregor Collection in the Library of the University of Virginia contains some notable early items on American Indians. Dr. T. H. Spence, Librarian of the Historical Foundation of the Presbyterian

Reformed Church, Montreat, N. C., called attention to an extremely rare pamphlet which describes Chickasaw and Choctaw towns, locates certain mounds, and contains notes on pigeon roosts (*A Brief History of the Mississippi Territory; to Which is Prefixed a Summary View of the Country between the Settlements on Cumberland River, and the Territory*, by Rev. James Hall, A. M., Salisbury (N. C.): 12 mo., pp. (2) 70, printed by Francis Coupée, 1801).

The second conference on Iroquois research, which Dr. Fenton organized in 1945, was again the outstanding event in Iroquois studies. The conference, held October 4, 5, and 6, in cooperation with the Allegany State Park Commission at Red House, N. Y., brought together anthropologists and historians interested in the Iroquois from the Northeastern States, Canada, and the Middle West. Charles E. Congdon of Salamanca, N. Y., and Merle H. Deardorff of Warren, Pa., were cohosts to the conference.

Dr. Fenton gave several lectures during the year on topics related to his work; on September 10 to the L. H. Morgan Chapter, New York State Archaeological Association, Rochester; October 15 to the Anthropological Society of Washington; December 12 to the Arts Club of Washington.

A chapter was completed for a forthcoming report of the American Folklore Society: "Research in American Folklore: Plains, Eastern Woodlands, and Contact Folklore between Indians and Colonial Settlers." Seneca Songs from Coldspring Longhouse was prepared as program notes to an album of records which the Library of Congress is publishing. Work was continued on a final draft of a report for the Smithsonian Miscellaneous Collections, *A Cayuga Condolence Cane with Pictographs Denominating the Founders of the Iroquois League*, a study which Dr. Fenton commenced several years ago at the request of the Cranbrook Institute of Science.

As a member of the Committee on International Cooperation in Anthropology, National Research Council, Dr. Fenton attended two meetings in Washington, and prepared a report on Anthropology during the War, VII: The Arab World (*American Anthropologist*, 1947, pp. 342-343). He relinquished secretaryship of the Anthropological Society of Washington, becoming vice president, and continued to give considerable time to the *Journal of the Washington Academy of Sciences*, as senior editor during 1947.

Publications.—Place names and related activities of the Cornplanter Senecas, V: The path to Conewango (*Pennsylvania Archaeologist*, vol. 16, pp. 42-56, April 1946).

Twí-yendagon (Wood eater) takes the heavenly path; on the death of Henry Redeye (1864?-1946), Speaker of the Coldspring Seneca

Longhouse (American Indian, American Association on Indian Affairs, vol. 3, No. 3, pp. 11-15, 1946).

Integration of Geography and Anthropology in Army Area Study Curricula (Bulletin American Association of University Professors, vol. 32, No. 4, pp. 696-706, winter, 1946).

Area studies in American universities (Commission on Implications, Armed Services Educational Programs, American Council on Education, xi+89 pp., Washington, 1947).

In addition, several reviews were prepared and published in the United States Quarterly Book List, and in other journals.

Dr. Philip Drucker, anthropologist, returned to his official station at Washington from Mexico at the beginning of the fiscal year. While awaiting the arrival of the collections from San Lorenzo Tenochtitlan, he began a study of the La Venta ceramic collections, excavated by the National Geographic Society-Smithsonian Institution expedition in the spring of 1942.

During the ensuing months he classified some 24,000 sherds from the site of La Venta, recording descriptive data and stratigraphic distributions which will be embodied in the final report on the culture represented at this key site of Olmec culture. At the conclusion of his study of these materials he prepared a brief paper entitled "Some Implications of La Venta Ceramics," for the Smithsonian Miscellaneous Collections.

On February 8, 1947, he proceeded from Washington to Mexico on a joint expedition of the National Geographic Society and the Smithsonian Institution. The purpose of this expedition was to make an archeological survey of the Pacific coast of the state of Chiapas, Mexico. From the time of his arrival in Tapachula, Chiapas, on February 16, until his departure from Tonalá, Chiapas, on May 24, he tested 15 archeological sites, obtaining from each collections of sherds ranging from 2,000 to 4,000 pieces on the average. Among these sites were several whose ceramics indicated a relationship with the Mixteca-Puebla area of the Highland, and which are probably to be attributed to the late pre-Conquest intrusions of the Nahuatl-speaking Pipil, colonies of whom penetrated as far southeastward as Nicaragua. Other sites yielded wares that indicate affiliation with more ancient horizons, one such linking very definitely with the oldest ceramic complex yet known from Guatemala Highland and coast: the Miraflores horizon. One of the outstanding finds of the survey was the discovery of a midden deposit over 3 meters in depth, containing pottery in the upper 1.2 m., and no trace of ceramics below this point. This site requires more extensive excavation than was possible during the survey, but it is quite possible that it may contain the earliest remains yet known from southern Mexico and Central America—perhaps pre-

ceramic and early ceramic horizons whose existence up to now has only been suspected but never demonstrated.

In the month of March, during the survey work, Dr. Drucker made a brief visit to Guatemala City where, through the courtesy of Drs. R. E. Smith and Edwin Shook of the Carnegie Institution, he was permitted to study pottery collections from the Guatemala Highlands and coast, in the Carnegie Institution Laboratory.

From Tonalá, Dr. Drucker proceeded to Mexico City to arrange for the exportation of the collections.

On June 9 Dr. Drucker arrived in Washington, D. C., where he was detailed to the River Basin Surveys project, under the direction of Dr. Frank H. H. Roberts, Jr., Associate Chief of the Bureau of American Ethnology. After a series of conferences with Dr. Roberts, Dr. Drucker proceeded on June 16 to the Pacific coast to take charge of archeological work in areas to be inundated by Bureau of Reclamation and Corps of Engineers dams in that area.

From July 1 through September 1 Dr. Gordon R. Willey, anthropologist, continued his field investigations, begun in March of 1946, as a member of the Virú Valley Expedition to northern Peru. The Virú program was a cooperative attempt, on the part of a group of anthropologists and a geographer, to study thoroughly a single valley of the Peruvian coast as a living unit through some 3,000 years of time. Archeological, geographical, and modern community studies were embraced in the project, which was under the direction of a steering committee of the Institute of Andean Research. As one of the major participants, Dr. Willey represented the Bureau on the steering committee. His own share of the research consisted of a survey of the prehistoric settlement patterns of the valley.

At the close of field operations in August over 300 sites had been studied from the point of view of community plan or settlement pattern. These sites were selected from all sections of the valley, and it is estimated that they represent a 25-percent sample of the total sites in the valley. All types of sites were included in the sample—cemeteries, dwelling units, fortifications, temples, and palaces. In addition particular attention was paid to prehistoric irrigation canals, evidences of past land utilization, and ancient roads. Preliminary analysis shows eight cultural periods to be represented. The survey was accomplished with the aid of jeep transportation and large-scale air photo-maps. A technique of site mapping, involving the use of an epidiascopic projector, was worked out with the air photos. The final report on this survey is now in preparation.

In addition to the settlement survey Willey also excavated at two burial sites, one in the upper and one in the lower valley. A report on the first of these sites has recently been published.

Early in August Willey took part in the Conference on Peruvian

Archeology held at Hacienda Chicln. At this time he presented a preliminary summary of his field results.

After the work in Virú was terminated, Dr. Willey made a brief visit to the Lambayeque Valley, north of the city of Trujillo, and examined collections in the important but little-known Bruning Museum. Returning south to Lima, he began a protracted trip by automobile, going from Lima to Caamaná and from there inland to the Lake Titicaca region. From Puno, on the lake, he proceeded north to Cuzco, Ayacucho, Huancayo, and returned to Lima. During this trip, which consumed some 2 to 3 weeks during the month of September, he visited numerous archeological sites. The most significant of these was the great architectural cluster at Huari near Ayacucho, the presumed center for the Middle Period Tiahuanacoid diffusion throughout Peru.

Upon his return to the United States in October Dr. Willey prepared several short papers and began the initial work of organizing notes, maps, and photographs on the Virú settlement-pattern study. He was engaged in this until April of 1947. For the last 3 months of the fiscal year he transferred his research interests toward the completion of a large monograph on the archeology of the Florida Gulf coast. This latter work, which embraces earlier field work of the author, as well as past field studies made by the Bureau in the Florida Gulf area, is intended as an over-all archeological summary of the region.

During the year Dr. Willey also served as assistant editor to the professional journal, *American Antiquity*, and submitted various news items on recent researches in archeology in South America. He held a similar position with the *Handbook of Latin American Studies* for which he prepared bibliographic extracts on some 50 titles dealing with South American archeology and wrote a general summary of recent archeological activities for the South American Continent during the year 1945.

In April Dr. Willey visited the Public Museum at Rochester, N. Y., where he delivered a lecture on the Virú work before the annual meeting of the New York State Archeological Society.

The following articles were written by Dr. Willey during the fiscal year 1946-47:

1. The Virú Valley Program in Northern Peru. *Acta Americana*, vol. 4, No. 4, 1946.
2. A Middle Period Cemetery in the Virú Valley, Northern Peru. *Journ. Washington Acad. Sci.*, vol. 37, No. 2, 1947.
3. Ecuadorean Figurines and the Ceramic Mold in the New World. (In press.)
4. Growth Trends in New World Cultures. (In press.)
5. An Interpretative Analysis of Horizon Styles in Peruvian Archeology. (In press.)

In addition, one book review was prepared for *Science*.

INSTITUTE OF SOCIAL ANTHROPOLOGY

The Institute of Social Anthropology was created in 1943 as an autonomous unit of the Bureau of American Ethnology to carry out cooperative training in anthropological teaching and research with the other American Republics. During the past year it was financed by transfers from the State Department, totaling \$113,150, from the appropriation "Cooperation with the American Republics, 1947." The major activities of the Institute of Social Anthropology during the fiscal year 1947 are as follows:

Washington office.—The Institute of Social Anthropology maintains headquarters in Washington for general planning, direction, and servicing of field projects. Dr. Julian H. Steward, founder and first Director of the Institute, resigned in September 1946 to accept a professorship at Columbia University. He was succeeded by Dr. George M. Foster, previously stationed in Mexico as social anthropologist of the Institute of Social Anthropology.

Brazil.—Cooperation with the Escola Livre de Sociologia e Politica began October 1, 1945, when Dr. Donald Pierson was assigned as representative of the Institute of Social Anthropology to Brazil. In February 1946 Dr. Kalervo Oberg was assigned as cultural anthropologist to cooperate with the Escola Livre.

In effect, the Institute has taken over and expanded a program which was begun under Dr. Pierson in 1940 and which has helped make the Escola Livre one of the most important social-science centers in South America.

During the fiscal year 1947 Institute of Social Anthropology scientists have given seven courses in sociology and anthropology, to supplement other courses given by local professors in the general field of the humanities. Advanced students have been given field training both in Mato Grosso among Indian groups, and among the rural peoples in the State of São Paulo, some distance from the city. This represents a very considerable educational advance, since for the first time advanced Brazilian students in anthropology and sociology, as a part of their regular courses, have been required to supplement theoretical classroom training with actual field experience. A number of papers by Smithsonian personnel and local students have been published in scientific series or journals other than Smithsonian volumes. Two monographs based on field work in 1947 are being prepared for publication by Smithsonian personnel in Smithsonian series, and Brazilian students also are preparing field notes for publication in Portuguese.

Smithsonian staff members have continued to guide the program of translating 200 articles and 13 books from English into Portuguese,

mentioned in last year's report. This work, financed by outside funds, is of great importance as an aid to teaching.

Colombia.—Cooperation with the Instituto Etnológico of the University of Cauca in Popayán began December 1, 1946. The Institute of Social Anthropology is represented by Dr. John H. Rowe who is engaged in cooperating with local personnel in the organization of this new institution and in giving three courses in anthropology to students. A short survey of the habitat of the Guambiano Indians has indicated that this is a satisfactory region for field work, which begins on a cooperative basis during the summer of 1947, with the participation of Colombian professors and students.

Mexico.—Cooperation with the Escuela Nacional de Antropología, a dependency of the Ministry of Education, began June 1, 1944. Dr. George M. Foster, social anthropologist, was replaced by Dr. Isabel Kelly, when the former was transferred to Washington. Dr. Stanley S. Newman, linguist, and Dr. Robert C. West, cultural geographer, are the other two Institute of Social Anthropology representatives in Mexico.

During the fiscal year 1947 these scientists have given five courses in social anthropology, linguistics, and cultural geography. The scene of field research was shifted in January 1947 from the Tarascan area, described in last year's report, to the Totonac Indian area east of Mexico City. Two monograph-length papers dealing with the Tarascans have been submitted by Smithsonian personnel for publication in the series of the Institute of Social Anthropology. A number of student papers have appeared in Mexican sources, and longer monographs in Spanish are ready for publication.

Peru.—Work began in Peru in January 1944, when that country had no institution devoted essentially to social science teaching and research. Subsequently a national center of social science, the Instituto de Estudios Etnológicos, of the Ministry of Education, has been established. Institute of Social Anthropology personnel cooperate with this Institute. During 1947 the Institute of Social Anthropology was represented in Peru by F. Webster McBryde, cultural geographer, and Dr. Allan Holmberg, social anthropologist, who arrived in July 1946 to succeed Dr. Harry Tschopik, Jr.

A party of six students and one professor accompanied Institute of Social Anthropology personnel to the Virú Valley in northern Peru for ethnographical and geographical field work during the months January to April 1947. Under the guidance of the Smithsonian scientists this material is now being prepared for publication. Courses also are being given in the Instituto de Estudios Etnológicos. In addition, the cultural geographer has aided in the reorganization of the

Geographical Society of the University of San Marcos in Lima, and in establishing the teaching curriculum of this department.

Publications.—One monograph of the series Publications of the Institute of Social Anthropology appeared in June 1947—Publication No. 3, *Moche, a Peruvian Coastal Community*, by John Gillin. Publication No. 4, *Cultural and Historical Geography of Southwest Guatemala*, by Felix Webster McBryde, Publication No. 5, *Highland Communities of Central Peru: A Regional Survey*, by Harry Tschopik, Jr., and Publication No. 6, *Empire's Children: the People of Tzintzuntzan*, by George M. Foster, were in proof. Publication No. 7, *Cultural Geography of the Modern Tarascan Area*, by Robert C. West, and Publication No. 8, *Sierra Popoluca Speech*, Mary L. Foster and George M. Foster, were edited and sent to the printer. Mrs. Eloise B. Edelen of the editorial staff of the Bureau of American Ethnology, did the editorial work on these publications.

RIVER BASIN SURVEYS

The River Basin Surveys were instituted in the fall of 1945 as a unit of the Bureau of American Ethnology. They were organized to carry into effect a memorandum of understanding between the National Park Service and the Smithsonian Institution. This memorandum provided for surveys to determine the extent and nature of archeological and paleontological remains occurring in areas to be flooded by the construction of dams by the Bureau of Reclamation and the Corps of Engineers, United States Army. The memorandum was signed on August 7, 1945, by Newton B. Drury, Director of the National Park Service, and on September 8, 1945, by Alexander Wetmore, Secretary of the Smithsonian Institution, and was approved by Harold L. Ickes, Secretary of the Interior, on October 9, 1945.

The first actual field work got under way in July 1946. A transfer of \$20,000 at the end of May 1946, by the Bureau of Reclamation through the National Park Service, provided the necessary funds for starting survey parties in the Missouri Basin. An additional \$40,000 subsequently was made available by the Bureau of Reclamation for work in this area during fiscal 1947. In September 1946 \$27,000 was transferred by the Corps of Engineers, through the National Park Service, for surveys outside of the Missouri Basin, and in March 1947 \$4,500 was transferred by the Bureau of Reclamation for surveys in the Columbia-Snake Basin. The Missouri Basin funds were for use in both Bureau of Reclamation and Corps of Engineers projects. The money provided by the Corps of Engineers was for Corps of Engineers projects only, while the Columbia-Snake Basin money was for use only in Bureau of Reclamation projects.

The first survey parties were started in the Missouri Basin. These were followed by investigations in Georgia, Virginia-North Carolina, Texas, California, and the Columbia-Snake Basin. Supervision and direction of the surveys in Georgia, Virginia-North Carolina, Texas, and California were carried on from the main office in Washington. Direction of the work in the Missouri Basin was from a field office located at Lincoln, Nebr., and the Columbia-Snake Basin investigations were based on a field office established at Eugene, Oreg.

The Bureau of Reclamation and the Corps of Engineers made the entire salvage program possible through the transfer of funds, but in addition both agencies contributed in no small degree to the successful inception of the surveys through their cooperation in other ways. Division and District Engineers and Bureau of Reclamation personnel did much to facilitate the work of the survey men in the field. In some areas transportation was provided, in others, necessary labor was furnished to aid in emergency excavations, and elsewhere temporary office space and storage facilities were made available at project headquarters. The genuine interest and desire to assist on the part of all with whom the members of the River Basin Surveys staff were associated in the various reservoir areas greatly aided the progress of the investigations. The planning of a Nation-wide archeological survey on a scale hitherto not believed possible became feasible with the transfer of funds. The cooperation of the National Park Service has been of marked benefit to the program and much credit is due to its officials for the obtaining of the necessary funds and for the pleasant relationship existing between all the agencies involved in the program.

Washington office.—Throughout the fiscal year the main office of the River Basin Surveys continued under the direction of Dr. Frank H. H. Roberts, Jr. Carl F. Miller, archeologist, joined the staff on November 6, 1946. Miss Madeleine A. Bachand was appointed clerk-stenographer on March 3, 1947, and continued to serve throughout the year.

Mr. Miller was preparing to leave for the Pearl River project at Bogalusa, La., on November 13, 1946, when a request was received from the district engineer to postpone this work indefinitely because the project had been stopped. Mr. Miller was then assigned to the study of proposed projects in the Middle Atlantic Division of the Corps of Engineers. He devoted his time to searching the literature for information about sites which might be involved by construction programs in Pennsylvania, Virginia, North Carolina, and West Virginia. During this period he also assisted the director in obtaining information about proposed projects of the Bureau of Reclamation in various parts of the country outside the Missouri Basin. On February 11,

1947, he left Washington for Richmond, Va., to confer with the officials at the Region 1 office of the National Park Service. From Richmond he proceeded to Norfolk, Va., on February 13, to confer with the district engineer, Corps of Engineers, about a survey of the Buggs Island project on the Roanoke River. He left Norfolk on February 14 and went to South Hill, Va., where he established headquarters. From that date until May 4 he surveyed all the Virginia and part of the North Carolina portion of the reservoir basin. He then returned to Washington and devoted the remainder of the fiscal year to preparing a preliminary report on the results of the survey and making recommendations and estimates for an excavation program in that area.

Missouri Basin.—The first steps in initiating investigations in the Missouri Basin were the establishment of field headquarters at Lincoln, Nebr., and the assembling of personnel to undertake the field surveys. Dr. Waldo R. Wedel, associate curator of archeology, United States National Museum, who had been detailed to the River Basin Surveys for that purpose, left Washington for Lincoln, Nebr., on July 8, 1946, and upon his arrival there began instructing the personnel recruited for the project and assembling equipment needed in the field. Through the courtesy of the University of Nebraska, office space was provided at the University's Laboratory of Anthropology. Later, additional space was made available for a laboratory. This arrangement continued throughout the year, and on June 30, 1947, both the field office and the project laboratory were housed in the basement of the Love Memorial Library on the university campus.

Actual reconnaissance started on August 3, 1946, and continued for a period of 7 weeks, at the end of which weather conditions made it necessary for the men to return to field headquarters. During this time, 3 parties of 2 men each, limited because of inadequate transportation, covered more than 13,000 miles and made preliminary investigations at 28 top priority Bureau of Reclamation projects and at 5 Corps of Engineers reservoirs. Since complete coverage of each reservoir basin was in no case possible, additional surveys were recommended for most of the units visited. One field party returned to the Harlan County Reservoir, Nebr., for a period of 5 weeks, October 16 to November 23, 1946, and with the aid of local labor tested a number of sites and removed material which was being damaged by erosion or being excavated by unauthorized collectors.

Dr. Waldo R. Wedel returned to Washington and to his regular duties at the National Museum on October 18, 1946. At this time Paul L. Cooper was designated as acting director for the Lincoln office and continued to serve in that capacity until May 21, 1947, when Dr. Wedel, who had again been detailed to the Surveys, returned to Lincoln and resumed his supervision of the Missouri Basin program.

During the fall and winter months at Lincoln the staff members prepared and completed preliminary appraisal reports covering 25 of the projects visited during the 1946 field season. By June 30 most of these reports had been distributed to the National Park Service, the Bureau of Reclamation, and the Corps of Engineers, or were ready to be mailed. A general paper entitled "Prehistory and the Missouri Valley Development Program: Summary Report on the Missouri River Basin Archeological Survey in 1946," written by Dr. Wedel, was published in April in the Smithsonian Miscellaneous Collections, volume 107, No. 6. Throughout this period the field laboratory cleaned and cataloged more than 10,000 archeological specimens gathered from 208 different sites, and in addition processed 426 photographic negatives and prepared approximately 2,200 prints for use in the reports. Maps were drawn showing the location of sites in each reservoir area, and the reports were mimeographed, assembled, and made ready for distribution.

Field work was resumed in the latter part of April when three archeological parties consisting of four men each and one paleontological party consisting of one man, started for various reservoir projects. The paleontologist subsequently was joined by a student assistant. In addition to further investigations in reservoir areas visited during the 1946 field season, other projects were added to the list, and by the end of the fiscal year a total of 44 Bureau of Reclamation and 6 Corps of Engineers projects had been surveyed. They are located in the States of Kansas, Nebraska, South Dakota, North Dakota, Wyoming, and Montana. All parties were in the field on June 30 and expected to continue throughout the summer. During this period Dr. Wedel directed operations in the Lincoln office and made several visits to the field parties at the locations where they were working. He also attended conferences between the regional officers of the National Park Service and Bureau of Reclamation and Corps of Engineers representatives.

The survey findings to date indicate that the Wyoming-Montana area contains few pottery-bearing sites. There, as in the western Dakotas, stone circles or "tipi-rings" are to be found in great numbers. Numerous outcrops of artifacts in strata exposed by stream cuttings are plentiful and occur at varying depths below the surface. Some of them give promise of containing material belonging to early occupations, possibly even those of the Paleo-Indian, and they may supply much needed data on that phase of Plains prehistory. Throughout northern Kansas and northwestern Nebraska pithouse villages attributed to semisedentary peoples predominate. Pottery-bearing sites as well as "tipi-rings" occur on the tributaries of the Missouri in North and South Dakota. Groups of mounds, village remains, and former camp sites suggesting a more sedentary type of

occupation than that west of the Missouri occur in the Jamestown-Devils Lake-Sheyenne area. Along the main stream of the Missouri in the Dakotas are some of the largest and best preserved and most impressive fortified Indian village sites in the United States. They contain much of the story of the development of Arikara, Mandan, and other upper Missouri cultures.

In many of the sites there is evidence of stratification and a sequence of cultures or a series of stages in cultural development. Others contain the record of prehistoric floods, of silting and soil erosion, of recurrent droughts, and fluctuation in climate. The excavation and the interpretation of the data contained in such sites will contribute greatly, not only to the story of the growth and development of the Plains Indians, but to our understanding of conditions similar to those met and overcome by the aboriginal peoples. For this reason the excavation and testing of several sites in three Bureau of Reclamation reservoirs was recommended for the fiscal year 1948, and for two important sites at one Corps of Engineers project.

J. Joseph Bauxar, archeologist, joined the Missouri Basin staff on July 15, 1946. From that date until August 3 he devoted his time to obtaining information on archeological remains in the Dakotas, from reports on previous excavations and surveys in that area, and in making preparations for work in the field. From August 3 until September 22, in company with Paul L. Cooper, he engaged in a preliminary reconnaissance of reservoir projects in Nebraska, South Dakota, North Dakota, and Montana. In these reservoir basins a total of 68 sites were examined, site locations and descriptions being recorded and surface collections made. During the laboratory period, from September 22 until April 24, 1947, Mr. Bauxar prepared preliminary reports for seven of the reservoirs, Angostura, Box Butte, Bronco, Crosby, Deslacs, Fort Randall, and Jamestown, and prepared a technical report entitled "Notes on the Archeology of the Upper James and Sheyenne River Valleys and the Devils Lake Area." From April 24 until May 7 he joined Wesley L. Bliss in preliminary surveys of three reservoirs in Kansas, one in Colorado, and five in Nebraska. During this period 25 sites, none of which had been recorded previously, were visited. From May 7 to June 2 the time was spent in collaborating with Wesley L. Bliss and Theodore E. White on a report entitled "Preliminary Appraisal of Archeological and Paleontological Resources of the Proposed Reservoirs in the Republican River Basin." On June 2 Mr. Bauxar left Lincoln, as a member of the field party under the direction of Paul L. Cooper, to make a reconnaissance of the Fort Randall Reservoir in South Dakota. This work was still in progress at the end of the fiscal year.

Wesley L. Bliss was appointed to the Missouri Basin staff as an archeologist on July 17, 1946. From July 17 to August 4 he was occupied in making preparations for field reconnaissance in Wyoming and Montana. He left Lincoln on August 4 and returned on September 22. In this period his party made preliminary surveys in six reservoir areas in Wyoming, one which lies both in Wyoming and Montana, and three in Montana. A total of 74 archeological and paleontological sites were found and recorded, and surface collections were made from each. The fall and winter months, September 22, 1946, until April 24, 1947, were spent at the Lincoln headquarters doing laboratory and library research and in writing preliminary reports. Reports were prepared for the Boysen, Tiber, and Medicine Lake Reservoirs. In addition, Mr. Bliss prepared a draft of a paper entitled "A Preliminary Appraisal of the Historic and Prehistoric Occupation of the Western Plains." Some revision and the checking of some material were needed to complete the paper. In the early spring of 1947 Bliss made several unofficial week-end visits with other members of the staff to archeological sites along the Missouri, north of Kansas City, and on the Big Blue River in Nebraska. These were for the purpose of obtaining a wider knowledge of archeological manifestations in the area. In one case the trip was instrumental in stopping the destruction of a group of mounds in the path of a real-estate subdivision. From April 24 to May 7, 1947, Mr. Bliss, in association with J. Joseph Bauxar, as previously noted, made a reconnaissance of nine proposed reservoirs in Kansas, Colorado, and Montana. He assisted in the preparation of the report on the Smokey Hill Sub-basin. On June 10 Mr. Bliss left Lincoln in charge of a field party and proceeded to the Glendo Reservoir in Wyoming where the remainder of the month was devoted to an intensive survey. At the end of the fiscal year, 30 sites had been located in addition to the ones noted during the preliminary reconnaissance in the summer of 1946.

Paul L. Cooper, archeologist, became a member of the Missouri Basin staff on July 15, 1946. Between that time and August 3 he assisted in the preparations for work in the field and made two trips to Omaha with Dr. Wedel for the purpose of consultation with members of the National Park Service and the Corps of Engineers. On August 3 he left Lincoln with J. Joseph Bauxar to make preliminary surveys at reservoir sites in Nebraska, South Dakota, North Dakota, and Montana. As previously noted, 68 archeological and paleontological sites were located during the course of this survey. Mr. Cooper returned to the Lincoln headquarters on September 22, and from October 7, 1946, to May 21, 1947, was in charge of the operation of the office and laboratory. During this period he planned and supervised the work of the project personnel, compiled monthly progress reports for the

summer field season and in analyzing the data and specimens collected and in preparing technical reports. The preliminary reports completed and mimeographed for distribution were on the Kirwin, Cedar Bluff, and Kanopolis Reservoirs in Kansas; the Enders, Harlan County, and Medicine Creek Reservoirs in Nebraska; and the Cherry Creek and Wray Reservoirs in Colorado. Mr. Kivett left Lincoln on May 3, 1947, in company with Jack T. Hughes. From then until May 19 they made a preliminary reconnaissance of six reservoirs in the Lower Platte River Sub-basin. A total of 19 previously unreported archeological sites were located during this period. After his return to Lincoln, Mr. Kivett prepared preliminary reports on the Lower Platte River Basin including all the information obtained from the six reservoirs visited. The period from June 1 to June 9 was spent in preparing for a preliminary reconnaissance of the Garrison Reservoir in North Dakota. Mr. Kivett and his party left Lincoln for North Dakota on June 9, and at the end of the year they were engaged in a survey of the Garrison Reservoir.

Theodore E. White, paleontologist, was appointed to the general River Basin Surveys staff on April 15, 1947. From that date until April 26 he devoted his time to studying collections of fossil material from the Missouri Basin in the United States National Museum. On April 27 he left Washington for Lincoln, Nebr., and on April 29 joined the Missouri Basin staff. He left Lincoln on May 2 and spent 6 days in a reconnaissance of proposed reservoir areas in the Lower Platte Sub-basin in north central Nebraska. During this time he visited seven reservoir basins finding fossil remains in only one. These were reworked material of little scientific value. Dr. White returned to the Lincoln headquarters on May 9 and left on May 13 to make a reconnaissance of the Republican and Smokey Hill Sub-basins in southwestern Nebraska, Kansas, and Colorado. This work continued until June 6, during which time he visited nine reservoirs in Nebraska, eight in Kansas, and two in Colorado. Seven of these sites were recommended for a more detailed survey on the basis of material found and the extent of the exposures. From June 6 to June 13 Dr. White worked at the Lincoln headquarters preparing reports and recommendations for the various reservoirs which he had examined. On June 13 he left Lincoln to examine proposed reservoir areas in the North Platte Sub-basin in Wyoming, the Cheyenne River Sub-basin in Wyoming and South Dakota, and smaller sub-basins in North and South Dakota. This reconnaissance lasted until June 28, and during the period three reservoirs were visited in Wyoming, six in South Dakota and four in North Dakota. Three of the reservoirs were recommended for more detailed investigation. White returned to Lincoln on June 28 and at the end of the fiscal year was preparing to start for further survey work in Wyoming and Montana.

Several students were employed as members of the various field parties for the Surveys beginning in June 1947. Robert L. Hall and Warren L. Wittry left Lincoln on June 2 with the Cooper party for the Fort Randall Reservoir in South Dakota, and at the end of the fiscal year were occupied in the survey of that area. John L. Essex, Gordon F. McKenzie, and Leo L. Stewart left Lincoln on June 9 as members of the Kivett party to make a reconnaissance of the Garrison Reservoir area in North Dakota. Mr. Essex had previously assisted Mr. Kivett in the work at the Harlan County Reservoir, Nebr., in November 1946. H. G. Pierce joined the Bliss party and left Lincoln on June 10 to assist in the survey at the Glendo Reservoir in Wyoming. He was still with the party at the end of the fiscal year. John C. Donohoe was employed on June 27 to assist the paleontologist, Dr. Theodore E. White.

Georgia.—Intensive survey of the Allatoona Reservoir area on the Etowah River in Georgia was carried on during the period November 12, 1946, to April 1, 1947. This survey was made by Joseph R. Caldwell, of the Division of Archeology, United States National Museum, who was detailed to the River Basin Surveys for that purpose. Caldwell located 206 archeological sites representing a record of thousands of years of diverse human cultures. Information obtained from this survey has added materially to the aboriginal history of that part of Georgia. Full knowledge, however, cannot be gained without excavation of some of the sites and the testing of others. In view of this the preliminary report, prepared by Mr. Caldwell and distributed to the National Park Service and the Corps of Engineers, recommends the excavation of 10 sites and the testing of 33 others. A request for further funds for this purpose has been made by the National Park Service to the Corps of Engineers, but at the end of the fiscal year no response had been received to the request. The specimens collected from the sites examined during the course of this survey were transferred to the National Museum on April 17, 1947.

Virginia-North Carolina.—The archeological reconnaissance of the Buggs Island project on the Roanoke River was carried on during the period of February 14 to May 1, 1947. This work was under the supervision of Carl F. Miller of the River Basin Surveys staff. During the course of the investigations, 94 archeological sites were located, 2 of which are extremely important as they appear to represent an eastern phase of the so-called Folsom culture which flourished in the western plains during the closing days of the last Ice Age. Other sites are pre-Colonial and some date from the early Colonial period. The latter are significant as they contain material characteristic of the late seventeenth-century contact with European culture and their investigation would throw considerable light on this little-known era. Excavation of 14 sites including the 2 eastern Folsom examples and the testing of

5 others has been recommended. A preliminary report on the Buggs Island Reservoir was completed but had not been processed for distribution at the end of the fiscal year.

Texas.—River Basin Surveys were started in Texas in March 1947 when, through the kindness and cooperation of the authorities, a field base and headquarters were established at the Department of Anthropology of the University of Texas at Austin. A survey of the Addicks Reservoir on South Mayde Creek, a tributary of Buffalo Bayou, near Houston, got under way March 27 and was still in progress at the close of the fiscal year. The Addicks project is not a reservoir in the true sense of the word, but a flood-prevention dam which will not retain water in its basin for more than 2 or 3 weeks at a time. As a consequence, most of the sites located in the basin will be available for study or excavation during most of the year. A series of nine sites were found, however, which were being destroyed by stream action, by construction work on the dam, or by indiscriminate and unauthorized digging. As a consequence, it was necessary to shift from a reconnaissance type of survey to an intensive testing procedure to salvage as much information as possible. Six of them were examined by digging a number of test pits in various portions of the areas which they covered, and subsequently two of the six were extensively excavated. The cooperation of the district engineer, Col. D. W. Griffiths, in supplying a crew of 10 men and a foreman for a period of several weeks made these excavations possible. One of the excavated sites consisted of a stratified midden containing a sequence of several cultural horizons. Work on the site was started on May 29 and completed on June 13. The second was started on June 16 and was still being dug at the end of the fiscal year. The information and material from these two sites will provide a fairly complete sequence showing the development of aboriginal culture in this area over a comparatively long period of time. During this period, the Indians progressed from a simple hunting group to a sedentary agricultural and pottery-making people. The data obtained are a significant contribution to the hitherto little-known pre-Columbian history of this part of Texas.

The Hords Creek Reservoir on Hords Creek, near Coleman, was surveyed during the period May 6 to May 17, 1947. Only eight sites were found in the reservoir basin. Six of them were burned rock middens and two were open camp sites. None gave indication of being of sufficient importance to warrant further investigation. Comparable material is available elsewhere in locations which will not be inundated. Unless construction work should reveal subsurface deposits of archeological material, no additional work will be required in this reservoir.

The Whitney Dam area on the Brazos River north of Waco was started on May 20 and was still in progress at the end of the fiscal

year. By June 30 a little over half of the basin had been covered. Numerous sites had been located and recorded, and a number had been trenched for additional information. Several small rock shelters were excavated to salvage material which was being disturbed by unauthorized collectors. Two laborers for digging test trenches and for excavating in the shelters were supplied by the resident engineer. The Brazos flows through an important archeological and paleontological area in Texas and much information is contained in the sites which will be flooded by the Whitney Dam. On the basis of data already obtained by the survey, a number of key sites will be recommended for excavation.

Joe Ben Wheat, archeologist, was appointed to the Surveys in Texas on March 20, 1947. He left Austin on March 25 for Galveston where he conferred with the district engineer and obtained information about the priority of various Corps of Engineer projects in Texas. From Galveston he proceeded to the Barker Reservoir near Houston. He found that the project was so near completion that there was no possibility of salvaging archeological information from that area. Construction on the Barker Dam had completely destroyed one large mound and obliterated any evidence of occupation areas. As a consequence he proceeded to the nearby Addicks Dam and began a survey of that area. After learning that much of the reservoir basin would be under water only at rare intervals, Mr. Wheat turned his attention to six sites in the immediate vicinity of the dam which would be destroyed either as a result of construction or by erosion from stream action. All these were tested, and from the information thus obtained he concluded that two of them should be excavated as they contained a sequence of materials showing a number of cultural changes. In this connection he went to Galveston on May 20 and conferred with Colonel Griffiths, the district engineer. As a result of this conference, Mr. Wheat was furnished an excavation crew, transportation, and the equipment necessary for conducting the excavations. He returned to Addicks on May 22, and was able to begin actual excavations on May 29. Digging was still in progress on June 30.

Robert L. Stephenson, archeologist, joined the Surveys in Texas on April 28. From that date until May 5 he worked at Austin, conferring with members of the Museum staff at the University, studying collections of archeological material, and making preparations for field reconnaissance. He left Austin on May 6 for the Hords Creek Reservoir. From May 7 through May 17 he examined the Hords Creek Reservoir Basin, locating and recording eight archeological sites. On May 18 he left Coleman for Waco where he conferred with Frank H. Watt, of the Central Texas Archeological Association, obtaining information about archeological sites along the Brazos River, and

particularly in the area to be flooded by the Whitney Dam. On May 19 he went to Whitney and conferred with the Resident Engineer. On May 20 he began the actual survey of the Whitney Dam area and continued with that work to the end of the fiscal year. During the course of his investigations he interviewed numerous local residents, obtaining all the information possible pertaining to the occurrence of archeological sites, and studied collections of artifacts which had been gathered from sites in the area. In addition he made note of various historic remains and obtained such data as were available about them. This information was forwarded to the regional office of the National Park Service at Santa Fe, N. Mex., for the benefit of the Park Service historians.

California.—Archeological surveys were started in California in May 1947. Through the cooperation of the Department of Anthropology of the University of California, at Berkeley, headquarters for the Surveys were made available. During the period from March 21 through June 28, 1947, six Corps of Engineers proposed reservoir basins were surveyed. They were Pine Flat on King's River, Terminus on Kaweah River, Success on Tule River, Isabella on Kern River, Folsom on American River, and Coyote Valley on the east fork of the Russian River. A total of 59 sites were located, and of this number 8 have been recommended for excavation or partial excavation.

Some immediate contributions to the archeological knowledge of California were derived from the surveys. Two aboriginal soapstone quarries and three pictograph sites, none of which had been described previously in archeological literature, were located. Surface collections of sherds of the unique and little-known Yokuts-Mona pottery will permit a more extensive description of the type from archeological sources than has previously been possible.

Franklin Fenenga, archeologist, was appointed to the California surveys on March 21. He made all the surveys in the six reservoirs listed above, prepared the preliminary reports on their archeological resources, and made recommendations for further work. On June 28 Mr. Fenenga left Berkeley, Calif., for Eugene, Oreg., and at the end of the fiscal year was starting a survey of the Detroit Reservoir in the Willamette Valley.

During the course of the surveys in California Mr. Fenenga employed several student assistants. Stephen C. Cappannari served in that capacity from May 8 to 11 inclusive; Francis A. Riddell, May 29–June 1, and June 12–15; Harry S. Riddell, Jr., April 17–20; and Clarence E. Smith, April 1–6, May 1–4 and 19–25.

Columbia-Snake Basin.—The program for surveys in the Columbia-Snake Basin was just getting under way at the close of the fiscal year. Dr. Philip Drucker, anthropologist on the regular staff of the Bureau

of American Ethnology, was detailed to the River Basin Surveys for the purpose of directing the work in this area. On June 30 he had established field headquarters at Eugene, where the Department of Anthropology of the University of Oregon provided office and laboratory space. Two field parties left Eugene on the morning of June 30, one to make a reconnaissance of the Detroit Reservoir, a Corps of Engineers project on the North Santiam River, in the Willamette Valley, Oreg., and the other to make investigations at the Cascade Reservoir on the North Fork Payette River in Idaho. Plans for the summer called for the survey of 4 Corps of Engineers and 12 Bureau of Reclamation projects.

Dr. Drucker left Washington on June 17, 1947, for San Francisco, Calif. He spent the day of June 18 at Lincoln, Nebr., studying the operational procedure being used in the Missouri Basin surveys and the laboratory arrangements for processing and cataloging specimens received from the field. He arrived in San Francisco on the 19th and spent the following 2 days in conference with the regional officers of Region 4 of the National Park Service and members of the Department of Anthropology at the University of California in Berkeley. On June 22 he left San Francisco for Portland, Oreg., arriving on the 23d. At Portland he spent 2 days discussing plans for the surveys with Regional Archeologist Louis R. Caywood of the National Park Service, regional officials of the Bureau of Reclamation, and representatives of the district engineer of the Corps of Engineers. At this time he also made arrangements for the field headquarters at Eugene. He returned to San Francisco on June 24 and reported the results of his trip to Portland to the regional office of the National Park Service. He also recruited personnel for the field parties and made arrangements for the shipment of equipment from Berkeley to Eugene. He left Berkeley on June 28, arriving at Eugene, Oreg., on the 29th. He left Eugene on June 30 with the field party proceeding to the Cascade Reservoir.

Clarence E. Smith, archeologist, was appointed to the Columbia-Snake Basin surveys on June 25. He spent the following 2 days assisting Dr. Drucker and Franklin Fenenga in making preparations for the summer's field work. On June 28 he left Berkeley in company with Fenenga for Eugene, Oreg. They arrived at Eugene on the 29th and on the morning of the 30th left for the Detroit Reservoir.

Richard D. Daugherty, archeologist, was appointed to the Columbia-Snake Basin staff on June 30, and left the same day for the Cascade Reservoir in Idaho.

Francis A. Riddell joined the Surveys staff on June 26, as field assistant. He left Berkeley, Calif., on June 28 and arrived at Eugene, Oreg., on June 29. On June 30 he left Eugene in company with Mr. Daugherty and Mr. Drucker for the Cascade Reservoir.

Cooperating institutions.—The River Basin Surveys have been fortunate in receiving wholehearted cooperation from local institutions in many portions of the country. Not only has space for field offices and laboratories been provided together with the assistance and advice of members of the various staffs, as at the University of Nebraska, the University of Texas, the University of California, and the University of Oregon, but in a number of cases units in the survey program have been taken over and are being worked by universities and local organizations. This active cooperation has relieved the River Basin Surveys of a considerable burden and has made for more rapid progress throughout the country as a whole.

In Pennsylvania the Pennsylvania Historical and Museum Commission helped with the program. The University of Kentucky assumed responsibility for investigations at the Wolf Creek and Dewey Reservoir projects in that State. The Alabama Museum of Natural History conducted surveys along the lower Chattahoochee River Basin in Alabama in areas which will be inundated. The Ohio State Museum at Columbus investigated Corps of Engineers projects in that State. The University of Missouri, in cooperation with the Missouri Resources Museum and the Missouri Archeological Society, started surveys and excavations in that portion of the Bull Shoals Reservoir, on the White River, which lies in Missouri and at several Corps of Engineers projects on the Osage River. The Department of Anthropology of the University of Chicago and the Illinois State Museum at Springfield agreed to cooperate in a survey of the Illinois River Basin where 17 Corps of Engineers projects are proposed. The University of Oklahoma examined and reported on two reservoirs, one of which, the Wister, will inundate extensive and important archeological material. The University of Nebraska cooperated both in the search for and the excavation of paleontological material and in archeological reconnaissance. The Nebraska State Historical Society assisted in the survey work and also did some digging in sites which will be destroyed by construction work. The South Dakota Historical Society did some survey work and also some excavation. The University of North Dakota and the North Dakota Historical Society cooperated in making a survey at the Heart Butte Reservoir and in testing a number of sites in that area. The University of Colorado assumed responsibility for a survey of eight reservoir basins in the Colorado-Big Thompson project and for more intensive investigation at the Wray Reservoir in eastern Colorado. The University of Denver planned surveys of a number of reservoirs in the Blue River-South Platte project and of two in the Arkansas River Basin south of Pueblo. Western State College took over the examination of a group of reservoirs along the Gunnison River in western Colorado.

The Archeological Survey Association of Southern California, sponsored by a number of museums in that area, started the investigation of a number of Corps of Engineers projects in southern California. The University of Washington surveyed a number of proposed reservoir basins in that State and made all the information available to the Columbia-Snake Basin group at Eugene. It also did some excavation work.

The Reports of Progress prepared by the cooperating organizations are sent to the River Basin Surveys for coordination and are then forwarded to the National Park Service. All the information obtained thus becomes a part of the record of the River Basin Surveys in general.

EDITORIAL WORK AND PUBLICATIONS

The editorial work of the Bureau continued during the year under the immediate direction of the editor, M. Helen Palmer. There were issued one Annual Report and one Publication of the Institute of Social Anthropology, as listed below.

Sixty-third Annual Report of the Bureau of American Ethnology, 1945-46. 12 pp.

Institute of Social Anthropology Publ. No. 3. *Moche, a Peruvian Coastal Community*, by John Gillin. 166 pp., 26 pls., 8 figs., 1 map.

The following publications were in press at the close of the fiscal year:

Bulletin 143. *Handbook of South American Indians*. Julian H. Steward, editor. Volume 3: *The Tropical Forest Tribes*. Volume 4: *The Circum-Caribbean Tribes*. Volume 5: *The Comparative Ethnology of the South American Indians*.

Institute of Social Anthropology Publ. No. 4. *Cultural and Historical Geography of Southwest Guatemala*, by Felix Webster McBryde.

Institute of Social Anthropology Publ. No. 5. *Highland Communities of Central Peru: A Regional Survey*, by Harry Tschopik, Jr.

Institute of Social Anthropology Publ. No. 6. *Empire's Children: the People of Tzintzuntzan*, by George M. Foster.

Institute of Social Anthropology Publ. No. 7. *Cultural Geography of the Modern Tarascan Area*, by Robert C. West.

Institute of Social Anthropology Publ. No. 8. *Sierra Popoluca Speech*, by Mary L. Foster and George M. Foster.

Publications distributed totaled 7,948, as compared with 12,730 for the fiscal year 1945-46.

LIBRARY

The Library of the Bureau has continued in charge of the librarian, Miss Miriam B. Ketchum, assisted by M. L. Fiester, who was appointed March 17, 1947.

The total accessions in the library as of June 30, 1947, were 34,462. There were 148 new accessions during the fiscal year, by purchase, gift,

and exchange. Many of the foreign exchanges which lapsed during the war have again resumed, and good progress has been made in filling the gaps, brought about by the war, in periodical sets.

Cards on hand for domestic periodicals have been typed, and the shelf list for this classification is now complete. A beginning has been made on typing the cards for serial publications of domestic societies and institutions, and this will soon be finished.

The labeling of sets of publications of domestic societies and institutions and all the domestic periodicals has been completed, and the labeling of the foreign serial publications has begun.

ILLUSTRATIONS

From late fall of 1946 up to June 30, 1947, E. G. Cassedy, illustrator, spent most of the time, with the exception of time taken out to prepare weather graphs, work for the Editorial Division, and miscellaneous maps and plates, on the restoration of the old Indian negatives of the Bureau of American Ethnology. With the help of Mr. Brostrup this work has been progressing very satisfactorily and many negatives which were important historically and which were about to be lost have been preserved for coming generations.

ARCHIVES

Miss Mae W. Tucker continued the work of operating and cataloging the manuscript and photographic archives of the Bureau. In addition to furnishing material for routine requests, some special requests for photographic prints requiring urgent attention have been filled. Visitors desiring to consult material in the archives have been given the required assistance.

The greater part of the time has been given to work on the manuscript catalog which is being prepared for publication, to include all the unpublished manuscript material in the Bureau archives. The data for this catalog has been typed on individual cards for each item and is ready for final assembling.

A new file-print collection consisting of prints made from the re-photographed and retouched negatives in the Bureau collection has been started and will continue as the new prints are made. On Mr. Cassedy's recommendation, an extra set of prints is being made along with the file prints, this set to be preserved for possible emergency use.

Some time is necessarily required for research work in connection with both the manuscript material and the photographs.

SPECIAL PHOTOGRAPHIC RESTORATION PROJECT

The Bureau of American Ethnology ever since its inception in 1879 has maintained a collection of photographic negatives of North Ameri-

can Indians. The file had its origin with the famous "Jackson" collection of over 1,000 negatives which was brought to the Bureau by Major Powell from the directorship of the United States Geological Survey. This unique and valuable group has been supplemented by about 11,000 additional negatives obtained from various sources including the field trips of the first 40 years, the exposures made in Washington of the visiting Indian delegations, gifts, and purchases. Nowhere else in this country is there a more complete photographic record of the Indians who figured prominently in peace and war during the important opening of the West in the nineteenth century. In several instances the only known photographs of important characters of this period are in this collection.

The great bulk of this collection was made before 1900 in the early days of photography, and often under extremely adverse field conditions of heat and bulky weight. These factors have contributed toward a deterioration of the negative image. This deterioration fortunately has started around the edges of the negative and is progressing toward the center, still leaving the figure and facial characteristics quite legible. However, if allowed to go on unchecked this collection will have disintegrated unto uselessness.

During this fiscal year it was determined to inaugurate a systematic program of restoration and preservation of this unique collection. The continuous demand for reprints from these negatives, especially those being used for publication, made this restoration imperative.

In February 1947 the services of a photographer, John O. Brostrup, were obtained. The photographer and the scientific illustrator have begun the program of restoration and preservation of these negatives. The following system was devised and is being used in this work:

- (1) Chemical improvement and cleaning of the original negative.
- (2) Making a uniform enlarged print from the original negative, cropping out destroyed and objectionable background areas.
- (3) Restoration of missing areas, and improvement of backgrounds by the scientific illustrator with the minimum alteration necessary to preserve faithfully the original negative.
- (4) Copying the restored enlargement to uniform 8 by 10 inch size.
- (5) Printing of permanent file prints.

All the processing is being carried out with the intent of insuring as great a degree of permanence as possible.

First priority is being given those negatives which are needed to supply prints for pay orders, i. e., those for which there is an immediate demand. Second priority are those negatives which are in the most advanced stages of deterioration.

At the beginning of the work in February an inspection was made of each negative, and those requiring early restoration were listed.

A file of restored prints is being built up, and inspection in the offices of the Bureau of American Ethnology is invited.

COLLECTIONS

Collections transferred by the Bureau of American Ethnology to the Department of Anthropology, United States National Museum, during the fiscal year were as follows:

<i>Accession No.</i>	<i>Collection</i>
176066.	65 ethnological specimens from the Rio Vaupés in Colombia and Brazil. Collected by Paul H. Allen.
176157.	3 ethnological specimens from the Navaho Indians. Collected by Dr. John P. Harrington, at Fort Defiance, Ariz., in 1939.
176347.	1 ceremonial cane from the Iroquois Indians of Six Nations Reserve, Canada. Collected by J. N. B. Hewitt, June 1916.

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the *American Indians, both past and present, of both continents*. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Respectfully submitted.

M. W. STIRLING, *Chief*.

Dr. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the activities of the International Exchange Service for the fiscal year ended June 30, 1947.

Although shipping was suspended during September, October, and November because of shipping and trucking strikes, the allotment for transportation was practically exhausted by the end of March. Therefore it was necessary to curtail sharply shipping during the last 3 months of the fiscal year.

The number of packages received for transmission during the year was 703,798, an increase over the previous year of 163,296. The weight of these packages was 773,975 pounds, an increase of 301,676 pounds. The average weight of the individual packages is approximately 1 pound, 2 ounces, as compared to the average of the previous year of approximately 14 ounces—an indication that the institutions are still shipping material held during the war. The material received from both foreign and domestic sources for distribution is classified as shown in the following table:

	Packages		Weight	
	Sent abroad	Received from abroad	Sent abroad	Received from abroad
United States parliamentary documents sent abroad.....	375, 501		<i>Pounds</i> 177, 722	<i>Pounds</i>
Publications received in return for parliamentary documents.....		2, 754		6, 421
United States departmental documents sent abroad.....	129, 075		199, 315	
Publications received in return for departmental documents.....		6, 573		13, 996
Miscellaneous scientific and literary publications sent abroad.....	166, 009		262, 492	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States.....		23, 886		84, 029
Total.....	670, 585	33, 213	669, 529	104, 446
Grand total.....	703, 798		773, 975	

The packages are forwarded partly by mail direct to the addressees and partly by freight to the exchange bureaus. The number of boxes shipped was 2,578, a decrease of 539. Of the boxes shipped 638 were for depositories of full sets of the United States Government documents furnished in exchange for the official publications of foreign governments for deposit in the Library of Congress. The number of packages forwarded by mail was 164,305.

Of the material accumulated at the Institution during the war, there remained at the beginning of the fiscal year 196,082 pounds. This war backlog was reduced to 69,020 but owing to enforced decrease in shipments during the last quarter of the year the actual backlog at the end of the year was 110,998 pounds.

Consignments are now forwarded to all countries except Rumania and Yugoslavia. Shipments to these countries will probably be resumed during the coming year. The notable resumptions of exchange are with Germany and Japan, which were effected with the cooperation of the Civil Affairs Division of the War Department.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The number of sets of United States official publications received to be sent in return for the official publications sent by foreign governments for deposit in the Library of Congress is 93 (56 full and 37 partial sets). The depository for Germany has been changed as indicated in the list and the set formerly sent to the League of Nations is now sent to the United Nations.

DEPOSITORIES OF FULL SETS

ARGENTINA: Dirección de Investigaciones, Archivo, Biblioteca y Legislación Extranjero, Ministerio de Relaciones Exteriores y Culto, Buenos Aires.

AUSTRALIA: Commonwealth Parliament and National Library, Canberra.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

QUEENSLAND: Parliamentary Library, Brisbane.

SOUTH AUSTRALIA: Public Library of South Australia, Adelaide.

TASMANIA: Parliamentary Library, Hobart.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

AUSTRIA: National Library of Austria, Vienna.*

BELGIUM: Bibliothèque Royale, Bruxelles.

BRAZIL: Instituto Nacional do Livro, Rio de Janeiro.

CANADA: Library of Parliament, Ottawa.

MANITOBA: Provincial Library, Winnipeg.

ONTARIO: Legislative Library, Toronto.

QUEBEC: Library of the Legislature of the Province of Quebec.

CHILE: Biblioteca Nacional, Santiago.

CHINA: Ministry of Education, National Library, Nanking, China.

PEIPING: National Library of Peiping.

COLOMBIA: Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Ministerio de Estado, Canje Internacional, Habana.

CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.

DENMARK: Kongelige Danske Videnskabernes Selskab, Copenhagen.

EGYPT: Bureau des Publications, Ministère des Finances, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn.

FINLAND: Parliamentary Library, Helsinki.

*Added during the year.

FRANCE: Bibliothèque Nationale, Paris.

GERMANY: Öffentliche Wissenschaftliche Bibliothek, Berlin.*¹

GREAT BRITAIN:

ENGLAND: British Museum, London.

LONDON: London School of Economics and Political Science. (Depository of the London County Council.)

HUNGARY: Library, Hungarian House of Delegates, Budapest.

INDIA: Imperial Library, Calcutta.

IRELAND: National Library of Ireland, Dublin.

ITALY: Ministero della Pubblica Istruzione, Rome.

JAPAN: Imperial Library of Japan, Tokyo.¹

MEXICO: Secretaría de Relaciones Exteriores, Departamento de Información para el Extranjero, Mexico, D. F.

NETHERLANDS: Royal Library, The Hague.

NEW ZEALAND: General Assembly Library, Wellington.

NORTHERN IRELAND: H. M. Stationery Office, Belfast.

NORWAY: Universitets-Bibliothek, Oslo. (Depository of the Government of Norway.)

PERU: Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.

PHILIPPINES: National Library, Manila.*

POLAND: Bibliothèque Nationale, Warsaw.

PORTUGAL: Biblioteca Nacional, Lisbon.

RUMANIA: Academia Română, Bucharest.

SPAIN: Cambio Internacional de Publicaciones, Avenida Calvo Sotelo 20, Madrid.

SWEDEN: Kungliga Biblioteket, Stockholm.

SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.

TURKEY: Department of Printing and Engraving, Ministry of Education, Istanbul.

UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.

UNION OF SOVIET SOCIALIST REPUBLICS: All-Union Lenin Library, Moscow 115.

UKRAINE: Ukrainian Society for Cultural Relations with Foreign Countries, Kiev.

UNITED NATIONS: Library of the United Nations, Geneva, Switzerland.

URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

YUGOSLAVIA: Ministère de l'Education, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AFGHANISTAN: Library of the Afghan Academy, Kabul.

BOLIVIA: Biblioteca del Ministerio de Relaciones Exteriores y Culto, La Paz.

BRAZIL:

MINAS GERAES: Directoria Geral e Estatística em Minas, Belo Horizonte.

BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.

CANADA:

ALBERTA: Provincial Library, Edmonton.

BRITISH COLUMBIA: Provincial Library, Victoria.

NEW BRUNSWICK: Legislative Library, Fredericton.

NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.

PRINCE EDWARD ISLAND: Legislative and Public Library, Charlottetown.

SASKATCHEWAN: Legislative Library, Regina.

* Added during the year.

¹ Temporarily suspended.

- CEYLON:** Chief Secretary's Office, Record Department of the Library, Colombo.
- DOMINICAN REPUBLIC:** Biblioteca de la Universidad de Santo Domingo, Ciudad Trujillo.
- ECUADOR:** Biblioteca Nacional, Quito.
- GUATEMALA:** Biblioteca Nacional, Guatemala.
- HAITI:** Bibliothèque Nationale, Port-au-Prince.
- HONDURAS:**
 Biblioteca y Archivo Nacionales, Tegucigalpa.
 Ministerio de Relaciones Exteriores, Tegucigalpa.
- ICELAND:** National Library, Reykjavík.
- INDIA:**
BENGAL: Library, Bengal Legislature, Assembly House, Calcutta.
BIHAR AND ORISSA: Revenue Department, Patna.
BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.
BURMA: Secretary to the Government of Burma, Education Department, Rangoon.
PUNJAB: Chief Secretary to the Government of the Punjab, Lahore.
UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.
- IRAN:** Imperial Ministry of Education, Tehran.
- IRAQ:** Public Library, Baghdad.
- JAMAICA:** Colonial Secretary, Kingston.
- LIBERIA:** Department of State, Monrovia.
- MALTA:** Minister for the Treasury, Valleta.
- NEWFOUNDLAND:** Department of Home Affairs, St. John's.
- NICARAGUA:** Ministerio de Relaciones Exteriores, Managua.
- PANAMA:** Ministerio de Relaciones Exteriores, Panama.
- PARAGUAY:** Ministerio de Relaciones Exteriores, Sección Biblioteca, Asunción.
- SALVADOR:**
 Biblioteca Nacional, San Salvador.
 Ministerio de Relaciones Exteriores, San Salvador.
- SIAM:** Department of Foreign Affairs, Bangkok.
- VATICAN CITY:** Biblioteca Apostolica Vaticana, Vatican City, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

There are now being sent abroad 71 copies of the Federal Register and 65 copies of the Congressional Record. The countries to which these journals are being forwarded are given in the following list:

DEPOSITORIES OF CONGRESSIONAL RECORD AND FEDERAL REGISTER

ARGENTINA:

- Biblioteca del Congreso Nacional, Buenos Aires.
 Biblioteca del Poder Judicial, Mendoza.³
 Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
 Boletín Oficial de la República Argentina, Ministerio de Justicia e Instrucción Pública, Buenos Aires.

AUSTRALIA:

- Commonwealth Parliament and National Library, Canberra.
NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.
QUEENSLAND: Chief Secretary's Office, Brisbane.
WESTERN AUSTRALIA: Library of Parliament of Western Australia.

³ Federal Register only.

BRAZIL:

Biblioteca do Congresso Nacional, Rio de Janeiro.

Imprensa Nacional, Rio de Janeiro.²

AMAZONAS: Archivo, Biblioteca e Imprensa Publica, Manaus.

BAHIA: Governador do Estado da Bahia, São Salvador.

ESPIRITO SANTO: Presidencia do Estado do Espirito Santo, Victoria.

RIO GRANDE DO SUL: "A Federação," Porto Alegre.

SERGIPE: Biblioteca Publica do Estado de Sergipe, Aracajú.

SÃO PAULO: Imprensa Oficial do Estado, São Paulo.

BRITISH HONDURAS: Colonial Secretary, Belize.

CANADA:

Library of Parliament, Ottawa.

Clerk of the Senate, Houses of Parliament, Ottawa.

CUBA:

Biblioteca del Capitolio, Habana.

Biblioteca Publica Panamericana, Habana.²

EGYPT: Ministry of Foreign Affairs, Egyptian Government, Cairo.²

FRANCE:

Bibliothèque, Chambre des Députés, Paris.

Bibliothèque, Conseil de la République.*

Publiques de l'Institute de Droit Compare, University de Paris, Paris.²*

GREAT BRITAIN: Printed Library of the Foreign Office, London.

GREECE: Library, Greek Parliament, Athens.

GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.

HAITI: Bibliothèque Nationale, Port-au-Prince.

HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.

INDIA:

Civil Secretariat Library, Lucknow, United Provinces.²*

Legislative Assembly Library, Lucknow, United Provinces.*

Legislative Department, Simla.

IRELAND: Dail Eireann, Dublin.

ITALY: International Institute for the Unification of Private Law, Rome.²

MEXICO:

Dirección General de Información, Secretaría de Gobernación, Mexico, D. F.

Biblioteca Benjamin Franklin, Mexico, D. F.

AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.

CAMPECHE: Gobernador del Estado de Campeche, Campeche.

CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.

CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.

COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.

COLIMA: Gobernador del Estado de Colima, Colima.

DURANGO: Gobernador Constitucional del Estado de Durango, Durango.

GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.

GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.

JALISCO: Biblioteca del Estado, Guadalajara.

LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali.

MÉXICO: Gaceta del Gobierno, Toluca.

MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.

² Federal Register only.

² Congressional Record only.

* Added during the year.

- MORELOS**: Palacio de Gobierno, Cuernavaca.
NAYARIT: Gobernador de Nayarit, Tepic.
NUEVO LEÓN: Biblioteca del Estado, Monterrey.
OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.
PUEBLA: Secretaría General de Gobierno, Puebla.
QUEBÉTARO: Secretaría General de Gobierno, Sección de Archivo, Querétaro.
SAN LUIS POTOSÍ: Congreso del Estado, San Luis Potosí.
SINALOA: Gobernador del Estado, de Sinaloa, Culiacán.
SONORA: Gobernador del Estado de Sonora, Hermosillo.
TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.
TAMAULIPAS: Secretaría General de Gobierno, Victoria.
TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.
VERACRUZ: Gobernador del Estado de Veracruz, Departamento de Gobernación y Justicia, Jalapa.
YUCATÁN: Gobernador del Estado de Yucatán, Mérida.
NEW ZEALAND: General Assembly Library, Wellington.
PERU: Cámara de Diputados, Lima.
POLAND: Ministry of Justice, Warsaw.²
SPAIN: Diputación de Navarra, San Sebastian.
SWITZERLAND: Bibliothèque, Bureau International du Travail, Geneva.²
UNION OF SOUTH AFRICA:
 CAPE OF GOOD HOPE: Library of Parliament, Cape Town.
 TRANSVAAL: State Library, Pretoria.
URUGUAY: Diario Oficial, Calle Florida 1178, Montevideo.
VENEZUELA: Biblioteca del Congreso, Caracas.

FOREIGN EXCHANGE AGENCIES

Exchanges are sent to all countries except Rumania and Yugoslavia. The countries listed are those to which shipments are forwarded by freight. To other countries not appearing on the list, packages are forwarded by mail.

LIST OF AGENCIES

- AUSTRIA**: Austrian National Library, Vienna.
BELGIUM: Service des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.
CHINA: Bureau of International Exchange, National Central Library, Nanking.
CZECHOSLOVAKIA: Bureau des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1-100.
DENMARK: Institut des Échanges Internationaux, Bibliothèque Royale, Copenhagen K.
EGYPT: Government Press, Publications Office, Bulaq, Cairo.
FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsinki.
FRANCE: Service des Échanges Internationaux, Bibliothèque Nationale, 58 Rue de Richelieu, Paris.
GERMANY: Öffentliche Wissenschaftliche Bibliothek, Berlin.⁴

² Federal Register only.

⁴ Distribution under supervision of War Department.

GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 721 North Circular Road, Willesden, London, N. W. 2.

HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.

INDIA: Superintendent of Government Printing and Stationery, Bombay.

ITALY:

Ufficio degli Scambi Internazionali, Ministero della Pubblica Istruzione, Rome.

JAPAN:

International Exchange Service, Imperial Library of Japan, Uyen Park, Tokyo.⁴

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: General Assembly Library, Wellington.

NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.

PALESTINE: Jewish National and University Library, Jerusalem.

POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.

PORTUGAL: Secção de Trocas Internacionais, Biblioteca Nacional, Lisbon.

QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.

RUMANIA: Ministère de la Propagande Nationale, Service des Échanges Internationaux, Bucharest.

SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.

SPAIN: Junta de Intercambio y Adquisición de Libros y Revistas para Bibliotecas Públicas, Ministerio de Educación Nacional, Avenida Calvo Sotelo 20, Madrid.

SWEDEN: Kungliga Biblioteket, Stockholm.

SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Palais Fédérale, Berne.

TASMANIA: Secretary to the Premier, Hobart.

TURKEY: Ministry of Education, Department of Printing and Engraving, Istanbul.

UNION OF SOUTH AFRICA: Government Printing and Stationery Office, Cape Town, Cape of Good Hope.

UNION OF SOVIET SOCIALIST REPUBLICS: International Book Exchange Department, Society for Cultural Relations with Foreign Countries, Moscow, 56.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

YUGOSLAVIA: Section des Échanges Internationaux, Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

H. W. DORSEY, *Acting Chief.*

Dr. A. WETMORE,

Secretary, Smithsonian Institution.

⁴ Distribution under supervision of War Department.

APPENDIX 7

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1947.

The regular appropriation for the operations of the Zoo was \$393,420. A supplemental appropriation of \$39,100 for salary increases authorized by Congress was also available, making a total of \$432,500. Subject to minor changes in final bills, a total of \$425,748 was expended for all purposes and an unexpended balance of \$6,752 remains. Inability to fill many of the positions for considerable periods resulted in salary savings which were available to apply on salary increases that had been authorized by Congress, thereby reducing the amount that was needed in the supplemental appropriation.

During the war equipment had deteriorated and stocks of materials and supplies had become seriously depleted in many instances. By diligent search the Zoo has been able to replace or repair some of the equipment and replenish some of the supplies and materials. The close of the fiscal year finds the Zoo short as to many items, but as a whole in a definitely better condition than prevailed a year ago as to exhibition animals, personnel, equipment, materials, supplies, and general condition of structures and grounds.

During the past year a slight improvement in the supply of animals for exhibition has enabled the Zoo partially to replenish the stock.

Physical improvements included the completion of 370 square yards of sidewalk; surface treatment of nearly all the main roads, a small parking area opposite the large-mammal house, the road back of the bird house, and the service road from the silver-gull cage to the bird house. Excellent progress has been made in painting, which is a continuous operation in an establishment of the size and type of the National Zoological Park. The general appearance of the grounds has been very materially improved by pruning, clearing of underbrush, cutting down weeds, and renewing and mowing lawns, all of which had been seriously neglected during the war period. During the summer of 1946 excellent progress was made in fighting poison ivy by spraying with ammonium sulfamate. This procedure was continued during the summer of 1947, and already a great reduction in this pest is noticeable. The fight against poison ivy was greatly

facilitated by the cooperation of the Department of Agriculture, Bureau of Plant Industry, in lending a power spray. Before 1947 the Zoo has each year received numerous reports of ivy poisoning in the Park, but up to midsummer of 1947 no cases have been reported.

NEEDS OF THE ZOO

A small addition to the personnel is needed to enable the Zoo to carry on the work in an efficient manner and permit employees to take the leave to which they are legally entitled. The Zoo has been undermanned throughout the entire period of its existence, and with the adoption of the 40-hour week, the situation has become particularly acute.

As the years go by the need becomes more pressing for new buildings to replace antiquated, dilapidated structures that are still used to house animals. Preliminary planning has been taken up with the Public Works Administration for construction of these buildings when economic conditions justify.

The condition of the Administration Building, which is now about 142 years old and has had no major improvements or rehabilitation for many years, is such that it cannot be kept in presentable condition, and the excessive dampness is injurious to equipment, records, photographs, negatives, and books, as well as to the health of the employees who work in the building.

VISITORS

Before the war the attendance at the Park was much greater on Saturdays and Sundays than on the earlier days of the week. Since the war there has been a surprisingly uniform attendance throughout the week, even Monday and Tuesday consistently showing good attendance. Throughout the year it was noticeable that there was a consistent increased attendance of visitors over the previous year, the final tabulation showing an increase for the year of 358,341.

ESTIMATED NUMBER OF VISITORS FOR FISCAL YEAR 1947

July (1946).....	311, 000	February.....	64, 100
August.....	280, 000	March.....	203, 225
September.....	276, 700	April.....	374, 053
October.....	189, 200	May.....	343, 800
November.....	153, 300	June.....	356, 400
December.....	93, 950		
January (1947).....	84, 950	Total.....	2, 730, 678

Groups came to the Zoo from schools in 22 States, some as far away as Wisconsin, Indiana, and Louisiana.

NUMBER OF GROUPS FROM SCHOOLS

	Num- ber of groups	Num- ber in groups		Num- ber of groups	Num- ber in groups
Alabama.....	1	18	New Jersey.....	24	1,847
Connecticut.....	8	220	New York.....	28	2,580
Delaware.....	8	324	North Carolina.....	67	2,676
District of Columbia.....	202	6,017	Ohio.....	36	981
Florida.....	5 1	5 13	Pennsylvania.....	151	8,109
Georgia.....	28	1,164	South Carolina.....	32	1,079
Indiana.....	4	152	Tennessee.....	15	682
Louisiana.....	1	5 84	Virginia.....	282	14,647
Maine.....	1	314	West Virginia.....	17	659
Maryland.....	369	22,179	Wisconsin.....	1	85
Massachusetts.....	16	886			
Michigan.....	8	376	Total.....	1,303	65,081

About 2 p. m. each day the cars then parked in the Zoo are counted by the Zoo police and listed according to the State, Territory, or country from which they came. This is, of course, not a census of the cars coming to the Zoo but is valuable in showing the percentage of attendance by States of people in private automobiles. The tabulation for the fiscal year 1947 is as follows:

	Percent		Percent
Washington, D. C.....	30.6	North Carolina.....	1.8
Maryland.....	21.09	West Virginia.....	1.2
Virginia.....	20.04	California.....	1.1
Pennsylvania.....	4.2	New Jersey.....	1.1
New York.....	2.5	Maine.....	.9
Ohio.....	1.9	Florida.....	.9

The cars that made up the remaining 12.67 percent came from every one of the remaining States, as well as from Alaska, Alberta, Argentina, Australia, British Columbia, Canal Zone, Cuba, Hawaii, Manitoba, Mexico, New Brunswick, Nicaragua, Nova Scotia, Ontario, Panama, Quebec, Saskatchewan, and Sweden.

It is well known that District of Columbia, Maryland, and Virginia cars bring to the Zoo many people from other parts of the United States and of the world, but no figures are available on which to base percentages.

THE EXHIBITS

The quality of specimens on exhibition has been fairly satisfactory during the year. The total number of specimens on hand June 30, 1947, was 454 more than on the corresponding date in 1946, the principal increase being in the number of birds and amphibians.

The outstanding exhibits during the year were penguins. Four species, the emperor, macaroni, rock-hopper, and adolie, were brought from the Antarctic by the United States Naval Antarctic Expedition through the interest of Rear Adm. Richard E. Byrd and Admiral Richard H. Cruzen. Two other species, the Humboldt and jack-ass, were already in the Zoo or were obtained from other sources.



PENGUINS IN GLASS-FRONTED COLD-STORAGE ROOM IN NATIONAL ZOOLOGICAL PARK

Left to right: 1 emperor, 1 king, 2 macaroni, 2 jackass, 1 king, 1 macaroni. Photograph by Ernest P. Walker.



FIVE MACARONI AND TWO HUMBOLDT PENGUINS IN OUTDOOR POOL AT NATIONAL ZOOLOGICAL PARK

Photograph by Ernest P. Walker.

Thirty-four ocellated turkeys were brought to the Zoo by Dr. D. S. Newill, who had obtained them in Guatemala. These turkeys have been very rare in collections and make an interesting exhibit. Five were retained and the rest distributed by Dr. Newill to other zoos.

Other interesting birds were two gray hornbills from India, the first of the species to be exhibited in the United States.

Three specimens of Troost's turtle, two albino and one normally colored, were deposited by James Nelson Gowanloch. All were young, only about 2 inches in diameter, but were outstanding because of the extreme rarity of albino turtles. These are a beautiful light cream color through which shows the pattern of the normal coloration. They have pink eyes and a bright red spot on the neck that is characteristic of the species.

Exhibits of very small creatures of more than ordinary interest were three different species of tiny frogs: the green and black arrow-poison frogs, red and black frogs, and yellow and black atelopus.

Other additions to the collection that were of unusual interest were: A young great gray kangaroo, which was a gift from the people of Australia to the people of the United States and was flown to Washington on a nonstop flight September 30-October 1, 1946, from Perth, Australia, to Washington, D. C., by the United States Navy plane *Truculent Turtle*; a young Alaska brown bear received through the interest of members of the force of the Alaska Game Commission and the Fish and Wildlife Service; an Arabian gazelle presented to the Zoo by W. W. Shaffer; a spectacled bear from the Andes region, obtained by purchase; a baby potto born to a pair that had been brought to the Zoo by the Smithsonian-Firestone Expedition to Liberia in 1940; pigmy green cardinals; the short-legged lizard from Cuba; five young specimens of the giant salamander of Japan, which were received by the United States Army as a gift from the school children of Japan to the school children of the United States, particularly through the interest of Brig. Gen. John W. O'Brien, Chief, Scientific and Technical Division, GHQ, SCAP, and Dr. Austin Brues and Lieutenant Kelly. These were collected through Dr. Tadamichi Koga, Director, Uyeno Zoological Garden, Tokyo, Japan.

ACQUISITION OF SPECIMENS

Specimens for the Zoo collection are acquired by gift, deposit, purchase, and births or hatchings. While depositors are at liberty to remove the specimens that they deposit with the Zoo, many leave the specimens for the rest of their lives.

During the year the Zoo received a number of shipments of live specimens by air without a single loss. Some of these animals were rare or delicate, and had they been transported by the usual means,

might have died en route. The experiences of other zoos and animal dealers have been similarly successful, suggesting that shipment of live animals by air may be the most satisfactory method.

DEPOSITORS AND DONORS AND THEIR GIFTS

- Abrahamian, S. M., Washington, D. C., Pekin duck.
 Acorn Pet and Gift Shop, Washington, D. C., 2 canary X siskin hybrids, 2 cockatiels.
 Alaska Game Commission and U. S. Fish and Wildlife Service, Alaska brown bear.
 Allison, Mrs. E. K., Washington, D. C., ring-necked dove.
 Alston, Herbert, Washington, D. C., woodcock.
 Australia, People of, through U. S. Navy, great gray kangaroo.
 Bader, J., Washington, D. C., 2 domestic rabbits.
 Baum, Louis, Alexandria, Va., 2 doves.
 Beale, Mrs. S. H., Washington, D. C., 2 snapping turtles.
 Benedict, Mrs. Jeanne, Washington, D. C., box turtle.
 Berry, Lewis, Detective Bureau, Metropolitan Police Department, Washington, D. C., 4 horned lizards.
 Best, Mrs. Richard, Washington, D. C., sulphur-crested cockatoo.
 Billoch, J., Washington, D. C., double yellow-headed parrot.
 Blanchette, Richard, Takoma Park, Md., snapping turtle.
 Boldridge, Dr. F. M., Chester, S. C., chain king snake.
 Brady, Morris K., Washington, D. C., 13 red and black frogs.
 Brewster, Kingman, Washington, D. C., 2 wild turkeys.
 Brown, Rev. Dillard, Washington, D. C., 5 ring-necked doves.
 Brown, Robert Y., Department of State, Washington, D. C., 46 little spotted tinamou,* 5 great tinamou.*
 Burr, Donald H., Washington, D. C., pine or fence lizard.
 Calvin, Mrs. E. F., Daniels Park, Md., 2 Pekin ducks.
 Campbell, George R., Detroit, Mich., corn snake, chicken snake.
 Carey, Maj. T. J., % Postmaster, New Orleans, La., douroucoulis or owl monkey.
 Carlson, R. S., Edgewater, Md., Pekin duck.
 Carson, James, Alexandria, Va., mole.
 Cedar Hill Bird Farm, Landover, Md., screech owl, robin.
 Chappell, Richard H., Chief, Probation Court, Washington, D. C., domestic rabbit.
 Clow, Jakie, Chevy Chase, Md., Pekin duck.
 Coker, James L., Arlington, Va., horned lizard.
 Cook, Jay E., Baltimore, Md., 32 African clawed frogs.*
 Coolidge, Belle, Washington, D. C., domestic rabbit.
 Cowell, Jerry, Greenbelt, Md., spectacled caiman.
 Cox, T. S., Arlington, Va., alligator.
 Cullen, Rev. U. G., Woodstock College, Woodstock, Md., copperhead snake.
 Deese, Joe, Bethesda, Md., rhesus monkey,* woodchuck or ground hog.*
 Dunitz, Gratz D., Alexandria, Va., American coot.
 Dunlap, Capt. S. A., U. S. Embassy, Buenos Aires, Argentina, Argentine tree frog, 18 grass paroquets.
 Duryel, Dr. William R., Washington, D. C., 75 red salamanders.*
 Eller, A., Falls Church, Va., Pekin duck.
 Fleming, A. L., Falls Church, Va., Mississippi mud turtle, pilot snake.
 Foellmer, John and Richard, Washington, D. C., 2 Pekin ducks.

* Deposits.

Fohel, Arthur, Williamstown, N. J., green grass snake.
 Ford, B. F., Aspin Hill, Md., 2 sparrow hawks.
 Fowler, James H., Chevy Chase, Md., Texas diamond-backed rattlesnake.
 Freeman, Mrs. J. W., Washington, D. C., 2 Pekin ducks.
 Gala, Mrs. M., Washington, D. C., Pekin duck×mallard duck hybrid.
 Garrett, William S., Richmond, Va., double yellow-headed parrot.
 Gazin, Max, Washington, D. C., Pekin duck.
 George, Miss Jean, Washington, D. C., red fox.
 Gildea, Mrs. James E., Arlington, Va., 2 Pekin ducks.
 Glover, R. L., Washington, D. C., American bittern.*
 Goddard, Don, Wilson Teachers College, Washington, D. C., 2 golden hamsters.*
 Goeller, John, Washington, D. C., golden hamster.
 Gowanloch, James Nelson, Louisiana Department of Wildlife and Fisheries, New Orleans, La., 3 Troost's turtles (including 2 albinos).*
 Greenberg, Albert, Tampa, Fla., 6 climbing perch, 12 blind cave fish.
 Guliek, Mrs. Dorothy, Silver Spring, Md., 3 Pekin ducks.
 Hagenmaker, Charles, Suitland, Md., barn owl.
 Hanwood, Mrs. Virginia, Washington, D. C., 2 Pekin ducks.
 Harper, Donald W., Kensington, Md., pilot snake.
 Harrell, R. O., South Boston, Va., rhesus monkey.
 Hart, Joseph F., Washington, D. C., sparrow hawk.
 Hartgroves, Bill, Kensington, Md., painted turtle.
 Hayes, Mrs. William J., Washington, D. C., Pekin duck.
 Hegener Research, Sarasota, Fla., 6 hutias.
 Heinz, J. E., Washington, D. C., Pekin duck.
 Hersey, Lt. J., Arlington, Va., yellow-headed parrot.
 Hines, Mrs. M., Hyattsville, Md., diamond dove, Cuban ground dove, Cuban tanager.
 Hubbs, C. L., La Jolla, Calif., 3 horned lizards.
 Hughes, Charles, Silver Spring, Md., pilot snake.
 Hughes, Thomas, Middletown, Del., sharp-shinned hawk.
 Hummel, David, Arlington, Va., titi monkey.*
 Ingham, Rex, Ruffin, N. C., Eastern chipmunk,* raccoon,* Swainson's hawk.*
 Jackley, A. M., Director, Reptile Control, Department of Agriculture, Pierre, S. Dak., 2 northern horned lizards.
 Jessup, Gordon L., Washington, D. C., pilot snake.
 Johnson, Cleris, Washington, D. C., barn owl.
 Jones, Mrs. R., Arlington, Va., weasel.
 Kelley, Miss Karen, Alexandria, Va., opossum.
 Kennard, Fred E., Hyattsville, Md., 2 muscovy ducks.
 Kimbell, Charles Lee, Hyattsville, Md., 2 horned lizards.
 Kincannon, W. Oliver, Chevy Chase, Md., 5 game fowl.*
 Klemetsen, P. N., Washington, D. C., alligator.
 Knop, P. T., Washington, D. C., 5 box turtles.
 Koerdel, Dr. Manuel-Malduado, Mexico, 5 axolotls.
 Kramer, Miss G. A., Washington, D. C., Pekin duck.
 Latona, Richard J., Washington, D. C., painted turtle, Cumberland terrapin.
 Lee, Jimmie, Washington, D. C., alligator.
 Leibel, Mrs. Leroy, Washington, D. C., grass paroquet.
 Leibold, Gordon M., Chevy Chase, Md., Florida king snake.
 Lemieux, Jerry, Washington, D. C., muscovy duck.
 Lund, Ruth and Diane, Washington, D. C., 2 Pekin ducks.

*Deposits.

Mackey, Helen N., Washington, D. C., Pekin duck.
 Majawer, Mrs. Lilly, Washington, D. C., cardinal.
 Markwith, Carl, Washington, D. C., domestic rabbit.
 Mattingly, W. E., Washington, D. C., 4 bantam fowl.
 Maurer, Misses Nan and Patsy Lou, Arlington, Va., 2 domestic rabbits.
 Mayer, J. D., Silver Spring, Md., 2 Pekin ducks.
 McCrassin, Broderick, Rockville, Md., 2 ring-necked pheasants.
 McDonald, Erling, Takoma Park, Md., muscovy ducks, screech owl.
 McKay, Raymond J., Washington, D. C., white-throated capuchin.
 Melville, E., Falls Church, Va., 3 Pekin ducks.
 Meyer, J. L., Silver Spring, Md., 2 Pekin ducks.
 Michel, Mr., Washington, D. C., Pekin duck.
 Miller, W. C., Front Royal, Va., 2 great horned owls.
 Miller, William H., Washington, D. C., Pekin duck.
 Miller, William W., Washington, Va., barn owl.
 Milne, A. M., Bethesda, Md., Pekin duck.
 Mitchell, Shirley J., Washington, D. C., rhesus monkey.
 Moise, Lawrence L., Washington, D. C., screech owl.
 Montague, Mrs. Claude, Washington, D. C., 2 grass paroquets.
 Moore, C. C., Washington, D. C., 14 grass paroquets.
 Naval Research Center, Bethesda, Md., rhesus monkey.*
 Nelson, Mrs. R. W., Coolidge High School, Washington, D. C., green tree frog.
 Newill, Dr. D. S., Conneltsville, Pa., 34 ocellated turkeys,* Reeves' pheasant, red jungle fowl, Swinhoe's pheasant, Nepal kaleege.
 Old, W. E., Jr., Norfolk, Va., 9 water moccasins.
 Orndorff, Mrs. B. F., Berwyn, Md., 3 Pekin ducks.
 Perkins, J. E., Back Bay National Wildlife Refuge, Pungo, Va., snow goose.
 Perry, Mrs., Washington, D. C., loggerhead turtle.
 Poe, Mrs. H. C., Washington, D. C., domestic rabbit.
 Pooley, S. M., National Institute of Health, Bethesda, Md., 20 golden hamsters, cotton rat.
 Potter, Lincoln, Chevy Chase, Md., opossum.
 Prestor, Mrs. P. D., Gage School, Washington, D. C., 3 golden hamsters.*
 Pupils of the Okayama-Ken Grammar Schools, through Brig. Gen. John W. O'Brien, Chief, Scientific and Technical Division, GHQ, SCAP, and Dr. Austin Brues and Lieutenant Kelly, collected through Dr. Tadamichi Kogo, Director of the Ueno Zoological Garden, Tokyo, Japan, 5 giant Japanese salamanders.
 Quinter, M. G., Chevy Chase, Md., Pekin duck.
 Raccie, Eugene J., Washington, D. C., golden pheasant.
 Reed, Vernon, Washington, D. C., Pekin duck.
 Remsen, Mrs. D., 2 skunks.
 Riédel, Mrs. W. E., Hyattsville, Md., sparrow hawk.
 Robert, Miss Alice B., water snake.*
 Rowe, Mr. and Mrs. R. F., Washington, D. C., 2 ringed warbling finches.
 Roys, Harold, Sheffield, Mass., 2 timber rattlesnakes.
 Ruhe, Louis, New York, N. Y., rat snake, frog, eyra or yaguarondi.*
 Ruhel, Miss Mary L., Washington, D. C., queen or moon snake.
 Sakell, Ronald, Washington, D. C., 2 white mice.
 Sardo, Mrs. William, Silver Spring, Md., Pekin duck.
 Sawyer, T. R., Alexandria, Va., crab-eating macaque.
 Scaramuzza, L. C., Habana, Cuba, short-legged lizard.
 Schaefer, Ronald L., Washington, D. C., box turtle.

*Deposits.

- Schaub, Mrs. Anna E., Washington, D. C., double yellow-headed parrot.
 Shaffer, W. W., Hobbs, Md., Arabian gazelle.
 Shannon, Mrs. Frank, Washington, D. C., 2 Pekin ducks.
 Shields, William S., Greenbelt, Md., blue jay.
 Shostick, Robert, Washington, D. C., green snake.
 Silverman, Marion and Marlene, Washington, D. C., Pekin duck.
 Simpson, Mrs. Lillie W., Washington, D. C., domestic guinea pig.
 Slagle, Bobby, Lubbock, Tex., 6 horned lizards.
 Smith, Mrs. H., Washington, D. C., blue jay.
 Smith, Margaret C., Washington, D. C., 11 hooded laboratory rats.
 Snider, Mrs. George P., Silver Spring, Md., Pekin duck.
 Snyder, Freeman W., Washington, D. C., 3 red foxes.
 Spates, W. E., Jr., Washington, D. C., Pekin duck.
 Spiney, Mr., Washington, D. C., tarantula.
 Springer, Harriet R., Washington, D. C., 2 Pekin ducks.
 Stone, Carl G., Silver Spring, Md., red-bellied woodpecker, 2 painted turtles, spotted turtle, box turtle.
 Stroman, H. R., Jr., Washington, D. C., 2 Pekin ducks.
 Stultz, Robert, Falls Church, Va., pilot snake.
 Taurman, Bert, Richmond, Va., 2 red-shouldered hawks.
 Taylor, L. S., Bethesda, Md., 2 Pekin ducks.
 Thirteenth Police Precinct, Washington, D. C., 2 chain king snakes.
 Thomas, J., Washington, D. C., canary.
 Thomas, Jeanette, Washington, D. C., 2 domestic rabbits.
 Thomas, Dr. W. B. S., Dover-Foxcroft, Maine, 2 garter snakes, 2 green frogs.
 Three Oaks Bird Farm, Hyattsville, Md., 10 domestic pigeons.
 Tinsman, L. T., Washington, D. C., white-tufted marmoset.*
 Tribble, W. E., Washington, D. C., 2 Pekin ducks.
 Tureman, Dr. G. R., Sandston, Va., gray fox.
 Turner, William, Westwood, Md., duck hawk.*
 U. S. Antarctic Expedition 1946-1947, through Admiral Richard E. Byrd, 2 emperor penguins, 13 macaroni penguins, 6 rock-hopper penguins, 2 black swans.
 U. S. S. *Mount Olympus*, through courtesy of Admiral Richard E. Byrd and careful care of Mr. Jack Perkins, collected by crew members of the U. S. S. *Currituck*, under command of Capt. J. E. Clark, 2 adie penguins.
 Walker, Mrs. C. G., Clifton, Va., pilot snake.
 Wells, Mrs. Charles, Washington, D. C., opossum.
 Western, Lt. Comdr. O. C., U. S. N., Naval Medical School, Bethesda, Md., 2 horned lizards.
 White House, Washington, D. C., domestic lamb.*
 Widman, R. D., Washington, D. C., Cumberland terrapin, painted turtle.
 Wilkins, O. L., Washington, D. C., black snake.
 Williamson, C., Washington, D. C., hog-nosed snake, pilot snake, pigmy rattlesnake.
 Witt, Benton, Cabin John, Md., gray fox.
 Wood, J. S., Washington, D. C., 2 Pekin ducks.
 Young, Mrs. W., Takoma Park, Md., Pekin duck.
 Zardus, Maurice, Riverdale, Md., eastern diamond-backed rattlesnake, 2 copper-head snakes, cottonmouth moccasin, coral snake, 2 water snakes, 4 pigmy rattlesnakes.
 Zetek, James, Balboa, C. Z., 53 yellow atelopos, 100 arrow-poison frogs, 10 basilisks.
 Zinkham, Dr. and Mrs. A. M., Washington, D. C., horned lizard.

*Deposits.

BIRTHS AND HATCHINGS

MAMMALS

Scientific name	Common name	Number
<i>Ammotragus lervia</i>	Aoudad.....	3
<i>Axis axis</i>	Axis deer.....	2
<i>Bibos gaurus</i>	Gaur.....	1
<i>Bison bison</i>	American bison.....	3
<i>Bos taurus</i>	British Park cattle.....	1
<i>Capromys pilorides</i>	Hutia.....	4
<i>Cebus capucinus</i>	White-throated capuchin.....	1
<i>Cercopithecus aethiops sabaeus</i> × <i>C.a. pygerythrus</i>	Hybrid green guenon × vervet guenon.....	1
<i>Cervus canadensis</i>	American elk.....	1
<i>Cervus nippon</i>	Japanese deer.....	1
<i>Cheropsis liberiensis</i>	Pigmy hippopotamus.....	1
<i>Cynomys ludovicianus</i>	Plains prairie dog.....	8
<i>Dama dama</i>	Fallow deer.....	2
<i>Dama dama</i>	White fallow deer.....	2
<i>Dasyprocta prymnolopha</i>	Agouti.....	1
<i>Felis concolor</i>	Puma.....	3
<i>Giraffa camelopardalis</i>	Nubian giraffe.....	1
<i>Hippopotamus amphibius</i>	Hippopotamus.....	1
<i>Lama glama guanicoe</i>	Guanaco.....	1
<i>Odocoileus virginianus</i>	Virginia deer.....	2
<i>Ovis europaea</i>	Mouflon.....	1
<i>Periodicticus potto</i>	Potto.....	1
<i>Poephagus grunniens</i>	Yak.....	1
<i>Procyon lotor</i>	Raccoon.....	2
<i>Thalartcos maritimus</i> × <i>Ursus middendorffi</i>	Hybrid bear.....	2

BIRDS

<i>Anas platyrhynchos</i>	Mallard duck.....	45
<i>Chenopsis atrata</i>	Black swan.....	6
<i>Fulica americana</i>	American coot.....	4
<i>Gallus</i> sp.....	Fighting fowl.....	12
<i>Gallus gallus</i>	Red jungle fowl.....	8
<i>Pavo cristatus</i>	Peafowl.....	7
<i>Turtur risorius</i>	Ring-necked dove.....	18

REPTILES

<i>Agkistrodon bilineatus</i>	Mexican moccasin.....	17
<i>Epicrates cenchris</i>	Rainbow boa.....	12
<i>Natrix</i> sp.....	Water snake.....	20
<i>Sceloporus undulatus</i>	Pine or fence lizard.....	6

MOLLUSKS

<i>Achatina achatina</i>	Giant land snail.....	5
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The birth of the rainbow boas makes the third generation in the Zoo, their grandparents having been brought from British Guiana in 1931.

ANIMALS IN THE NATIONAL ZOOLOGICAL PARK, JUNE 30, 1947

MAMMALS

MARSUPIALIA

Scientific name	Common name	Number
Didelphiidae:		
<i>Didelphis virginiana</i>	Opossum.....	3
Phalangeridae:		
<i>Petaurus breviceps</i>	Lesser flying phalanger.....	2
Macropodidae:		
<i>Dendrolagus inustus</i>	New Guinea tree kangaroo.....	2
Phascologyidae:		
<i>Vombatus ursinus</i>	Flinders Island wombat.....	1

INSECTIVORA

Erinaceidae:		
<i>Erinaceus europaeus</i>	European hedgehog.....	4

CARNIVORA

Felidae:		
<i>Felis chaus</i>	Jungle cat.....	1
<i>Felis concolor</i>	Puma.....	7
<i>Felis concolor patagonica</i>	Patagonian puma.....	1
<i>Felis concolor</i> × <i>F. c. patagonica</i>	Hybrid North American × South American puma.....	4
<i>Felis leo</i>	Lion.....	3
<i>Felis onca</i>	{ Jaguar.....	3
	{ Black jaguar.....	1
<i>Felis pardalis</i>	Ocelot.....	2
<i>Felis pardus</i>	{ Indian leopard.....	1
	{ Black Indian leopard.....	2
<i>Felis temminckii</i>	Golden cat.....	1
<i>Felis tigris</i>	Bengal tiger.....	2
<i>Felis tigris longipilis</i>	Siberian tiger.....	1
<i>Felis tigris sumatrae</i>	Sumatran tiger.....	3
<i>Herpailurus yaguarondi</i>	Eyra or yaguarondi.....	1
<i>Lynx rufus</i>	Bay lynx.....	1
<i>Oncifelis geoffroyi</i>	Geoffroy's cat.....	3
<i>Oncilla pardinoides</i>	Lesser tiger cat.....	1
Viverridae:		
<i>Arctictis binturong</i>	Binturong.....	1
<i>Civetticivis civetta</i>	African civet.....	1
<i>Myonax sanguineus</i>	Dwarf civet.....	1
<i>Paradoxurus hermaphroditus</i>	Small-toothed palm civet.....	3
Hyenidae:		
<i>Crocuta crocuta germinans</i>	East African spotted hyena.....	1
Canidae:		
<i>Canis dingo</i>	Dingo.....	2
<i>Canis latrans</i>	Coyote.....	1
<i>Canis latrans</i> × <i>familiaris</i>	Coyote and dog hybrid.....	1
<i>Canis lupus nubilus</i>	Plains wolf.....	2
<i>Canis niger rufus</i>	Texas red wolf.....	1
<i>Cuon javanicus sumatrensis</i>	Sumatran wild dog.....	1

Scientific name	Common name	Number
Canidae—Continued		
<i>Dusicyon (Cerdocyon) thous</i>	South American fox.....	1
<i>Nyctereutes procyonoides</i>	Raccoon dog.....	2
<i>Urocyon cinereoargenteus</i>	Gray fox.....	10
<i>Vulpes fulva</i>	Red fox.....	11
Procyonidae:		
<i>Nasua narica</i>	Coatimundi.....	9
<i>Nasua nasua</i>	Red coatimundi.....	1
<i>Nasua nelsoni</i>	Nelson's coatimundi.....	1
<i>Potos flavus</i>	Kinkajou.....	5
<i>Procyon lotor</i>	{ Raccoon.....	3
	{ Black raccoon.....	4
	{ Raccoon (albino).....	1
Bassariscidae:		
<i>Bassariscus astutus</i>	Ring-tail or cacomistle.....	2
Mustelidae:		
<i>Grissonella huronax</i>	Grison.....	1
<i>Lutra canadensis vaga</i>	Florida otter.....	1
<i>Lutra (Micraonyx) cinerea</i>	Small-clawed otter.....	1
<i>Martes (Lamprogale) flavigula henricii</i>	Asiatic marten.....	1
<i>Meles meles leptorynchus</i>	Chinese badger.....	1
<i>Mellivora capensis</i>	Ratel.....	1
<i>Mephitis mephitis nigra</i>	Skunk.....	7
<i>Mustela eversmanni</i>	Ferret.....	1
<i>Mustela frenata noveboracensis</i>	Weasel.....	1
<i>Tayra barbara barbara</i>	White tayra.....	2
<i>Tayra barbara senilis</i>	Gray-headed tayra.....	1
Ursidae:		
<i>Euarctos americanus</i>	Black bear.....	4
<i>Euarctos thibetanus</i>	Himalayan bear.....	1
<i>Helarctos malayanus</i>	Malay or sun bear.....	1
<i>Melursus ursinus</i>	Sloth bear.....	1
<i>Thalarctos maritimus</i>	Polar bear.....	3
<i>Thalarctos maritimus</i> × <i>Ursus middendorffi</i>	Hybrid bear.....	4
<i>Tremarctos ornatus</i>	Spectacled bear.....	1
<i>Ursus</i> sp.....	Alaska brown bear.....	1
<i>Ursus arctos</i>	European brown bear.....	1
<i>Ursus arctos meridionalis</i>	Caucasus brown bear.....	1
<i>Ursus gyas</i>	Alaskan Peninsula bear.....	2
<i>Ursus middendorffi</i>	Kodiak bear.....	3
<i>Ursus sitkensis</i>	Sitka brown bear.....	3

PINNIPEDIA

Otariidae:		
<i>Zalophus californianus</i>	Sea lion.....	2
Phocidae:		
<i>Phoca vitulina richardii</i>	Pacific harbor seal.....	2

PRIMATES

Lemuridae:		
<i>Galago demidovii</i>	Least galago.....	1
<i>Lemur mongoz</i>	Mongoose lemur.....	2

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Saimiridae:		
<i>Saimiri sciureus</i>	Titi monkey.....	2
Cebidae:		
<i>Aotus trivirgatus</i>	Douroucouli or owl monkey ..	5
<i>Ateles geoffroyi vellerosus</i>	Spider monkey.....	8
<i>Cebus apella</i>	Gray capuchin.....	2
<i>Cebus capucinus</i>	White-throated capuchin.....	3
<i>Cebus fatuellus</i>	Weeping capuchin.....	3
<i>Lagothrix lagotricha</i>	Woolly monkey.....	1
Cercopithecidae:		
<i>Cercocebus aterrimus</i>	Black-crested mangabey.....	1
<i>Cercocebus fuliginosus</i>	Sooty mangabey.....	2
<i>Cercocebus torquatus lunulatus</i>	White-crowned mangabey.....	1
<i>Cercopithecus aethiops pygerythrus</i>	Vervet guenon.....	2
<i>Cercopithecus aethiops sabaeus</i>	Green guenon.....	8
<i>Cercopithecus aethiops sabaeus</i> × <i>C. pygerythrus</i>	Hybrid green guenon × vervet guenon.....	1
<i>Cercopithecus cephus</i>	Moustached guenon.....	2
<i>Cercopithecus diana</i>	Diana monkey.....	3
<i>Cercopithecus diana roloway</i>	Roloway monkey.....	1
<i>Cercopithecus neglectus</i>	De Brazza's guenon.....	1
<i>Cercopithecus nictitans petaurista</i>	Lesser white-nosed guenon.....	2
<i>Cercopithecus sp.</i>	West African guenon.....	1
<i>Erythrocebus patas</i>	Patas monkey.....	1
<i>Gymnopyga maurus</i>	Moor monkey.....	1
<i>Macaca irus mordax</i>	Javan macaque.....	6
<i>Macaca lasiotis</i>	Chinese macaque.....	1
<i>Macaca mulatta</i>	Rhesus monkey.....	13
<i>Macaca nemestrina</i>	Pig-tailed monkey.....	2
<i>Macaca philippinensis</i>	Philippine macaque.....	4
<i>Macaca silene</i>	Wanderoo monkey.....	2
<i>Macaca sinica</i>	Toque or bonnet monkey.....	1
<i>Macacus irus</i>	Crab-eating macaque.....	1
Hylobatidae:		
<i>Hylobates agilis</i>	Sumatran gibbon.....	1
<i>Hylobates agilis</i> × <i>H. lar pileatus</i>	Hybrid gibbon.....	1
<i>Hylobates hoolock</i>	Hoolock gibbon.....	1
<i>Hylobates lar pileatus</i>	Black-capped gibbon.....	1
<i>Symphalangus syndactylus</i>	Siamang gibbon.....	1
Pongidae:		
<i>Pan troglodytes verus</i>	West African chimpanzee.....	2
RODENTIA		
Sciuridae:		
<i>Citellus beecheyi douglasii</i>	Douglas ground squirrel.....	3
<i>Cynomys ludovicianus</i>	Plains prairie dog.....	56
<i>Funisciurus leucostigma</i>	West African bush squirrel.....	3
<i>Glaucomys volans</i>	Flying squirrel.....	7
<i>Marmota monax</i>	Woodchuck or ground hog.....	4
<i>Tamias striatus</i>	Eastern chipmunk.....	1
Heteromyidae:		
<i>Dipodomys ordii</i>	Ord kangaroo rat.....	3

Scientific name	Common name	Number
Cricetidae:		
<i>Mesocricetus auratus</i>	Golden hamster.....	7
<i>Peromyscus leucopus</i>	White-footed or deer mouse.....	7
<i>Sigmodon hispidus</i>	Cotton rat.....	1
Muridae:		
<i>Meriones unguiculatus</i>	Mongolian gerbil.....	1
<i>Mus musculus</i>	White and other domestic mice.....	12
<i>Rattus norvegicus</i>	Hooded laboratory rat.....	11
Hystricidae:		
<i>Acanthion brachyurum</i>	Malay porcupine.....	3
<i>Atherurus africanus</i>	West African brush-tailed porcupine.....	3
<i>Thecurus crassispinis sumatrae</i>	Thick-spined porcupine.....	1
Myocastoridae:		
<i>Myocastor coypus</i>	Coypu.....	5
Capromyidae:		
<i>Capromys pilorides</i>	Hutia.....	5
Dasyproctidae:		
<i>Dasyprocta prymnolopha</i>	Agouti.....	1
<i>Dasyprocta punctata</i>	Speckled agouti.....	3
Chinchillidae:		
<i>Chinchilla chinchilla</i>	Chinchilla.....	4
<i>Lagidium viscaccia</i>	Peruvian viscacha.....	5
Caviidae:		
<i>Cavia porcellus</i>	Guinea pig.....	3
<i>Dolichotis patagona</i>	Patagonian cavy.....	1
LAGOMORPHA		
Leporidae:		
<i>Oryctolagus cuniculus</i>	Domestic rabbit.....	5
ARTIODACTYLA		
Bovidae:		
<i>Ammotragus lervia</i>	Aoudad.....	17
<i>Anoa fergusonii</i>	Mountain anoa.....	1
<i>Bibos gaurus</i>	Gaur.....	3
<i>Bison bison</i>	{ American bison.....	13
	{ Albino bison.....	1
<i>Bos indicus</i>	Zebu.....	4
<i>Bos taurus</i>	Domestic cow (Jersey).....	1
<i>Bos taurus</i>	West Highland or Kyloe cattle.....	4
<i>Bos tarus</i>	British Park cattle.....	6
<i>Bubalus bubalis</i>	Water buffalo.....	2
<i>Capra sibirica</i>	Ibex.....	1
<i>Cephalophus maxwellii</i>	Maxwell's duiker.....	1
<i>Cephalophus niger</i>	Black duiker.....	1
<i>Cephalophus nigrifrons</i>	Black-fronted duiker.....	2
<i>Hemitragus jemlahicus</i>	Tahr.....	5
<i>Oryx leucoryx</i>	Arabian oryx.....	2
<i>Ovis aries</i>	Woolless or Barbados sheep.....	1
<i>Ovis europaea</i>	Mouflon.....	4
<i>Poephagus grunniens</i>	Yak.....	5
<i>Pseudois nayaur</i>	Bharal or blue sheep.....	1
<i>Syncerus caffer</i>	African buffalo.....	2
<i>Taurotragus oryx</i>	Eland.....	2

Scientific name	Common name	Number
Cervidae:		
<i>Axis axis</i>	Axis deer.....	5
<i>Cervus canadensis</i>	American elk.....	5
<i>Cervus elaphus</i>	Red deer.....	4
<i>Cervus nippon</i>	Japanese deer.....	5
<i>Cervus nippon manchuricus</i>	Dybowsky deer.....	2
<i>Dama dama</i>	{ Fallow deer.....	13
	{ White fallow deer.....	15
<i>Odocoileus virginianus</i>	Virginia deer.....	6
Giraffidae:		
<i>Giraffa camelopardalis</i>	Nubian giraffe.....	4
<i>Giraffa reticulata</i>	Reticulated giraffe.....	1
Camelidae:		
<i>Camelus bactrianus</i>	Bactrian camel.....	3
<i>Camelus dromedarius</i>	Single-humped camel.....	1
<i>Lama glama</i>	Llama.....	1
<i>Lama glama guanico</i>	Guanaco.....	3
<i>Lama pacos</i>	Alpaca.....	2
<i>Vicugna vicugna</i>	Vicuña.....	1
Tayassuidae:		
<i>Pecari angulatus</i>	Collared peccary.....	1
Suidae:		
<i>Babirusa babirusa</i>	Babirusa.....	2
<i>Phacochoerus aethiopicus aeliani</i>	East African wart hog.....	2
<i>Sus scrofa</i>	European wild boar.....	2
Hippopotamidae:		
<i>Choeropsis liberiensis</i>	Pigmy hippopotamus.....	6
<i>Hippopotamus amphibius</i>	Hippopotamus.....	2
PERISSODACTYLA		
Equidae:		
<i>Equus burchellii antiquorum</i>	Chapman's zebra.....	2
<i>Equus grevyi</i> × <i>caballus</i>	Zebra-horse hybrid.....	1
<i>Equus kiang</i>	Asiatic wild ass or kiang.....	1
<i>Equus onager</i>	Onager.....	1
<i>Equus przewalskii</i>	Mongolian wild horse.....	3
<i>Equus zebra</i>	Mountain zebra.....	1
Tapiridae:		
<i>Acrocodia indica</i>	Asiatic tapir.....	2
Rhinocerotidae:		
<i>Rhinoceros unicornis</i>	Great Indian one-horned rhinoceros.....	1
PROBOSCIDAE		
Elephantidae:		
<i>Elephas maximus sumatranus</i>	Sumatran elephant.....	1
<i>Loxodonta africana oxyotis</i>	African elephant.....	1
EDENTATA		
Dasypodidae:		
<i>Chaetophractus villosus</i>	Hairy armadillo.....	1
<i>Euphractus sexcinctus</i>	Six-banded armadillo.....	1
Myrmecophagidae:		
<i>Myrmecophaga tridactyla</i>	Giant anteater.....	1

BIRDS

STRUTHIONIFORMES

Scientific name	Common name	Number
Struthionidae:		
<i>Struthio camelus</i>	Ostrich	2

RHEIFORMES

Rheidae:		
<i>Rhea americana</i>	Common rhea	3

CASUARIIFORMES

Casuariidae:		
<i>Casuarius casuarius aruensis</i>	Aru cassowary	1
<i>Casuarius uniappendiculatus occipitalis</i>	Island cassowary	1
<i>Casuarius uniappendiculatus uniappendi-</i> <i>clatus</i>	One-wattled cassowary	1
Dromiceidae:		
<i>Dromiceius novaehollandiae</i>	Common emu	2

SPHENISCIFORMES

Spheniscidae:		
<i>Aptenodytes forsteri</i>	Emperor penguin	1
<i>Eudyptes chrysolophus</i>	Macaroni penguin	11
<i>Eudyptes cristatus</i>	Rock-hopper penguin	2

TINAMIFORMES

Tinamidae:		
<i>Nothura maculosa</i>	Spotted tinamou	2

PELECANIFORMES

Pelecanidae:		
<i>Pelecanus californicus</i>	California brown pelican	2
<i>Pelecanus erythrorhynchus</i>	White pelican	5
<i>Pelecanus occidentalis</i>	Brown pelican	3
<i>Pelecanus roseus</i>	Rose-colored pelican	4

Phalacrocoracidae:		
<i>Phalacrocorax auritus albociliatus</i>	Farallon cormorant	1

CICONIIFORMES

Ardeidae:		
<i>Ardea herodias</i>	Great blue heron	2
<i>Ardea occidentalis</i>	Great white heron	1
<i>Egretta thula</i>	Snowy egret	5
<i>Hydranassa tricolor ruficollis</i>	Louisiana heron	1
<i>Notophox novaehollandiae</i>	White-faced heron	1
<i>Nyctanassa violacea cayennensis</i>	South American yellow-	
	crowned night heron	1
<i>Nycticorax nycticorax naevius</i>	Black-crowned night heron	30
Cochleariidae:		
<i>Cochlearius cochlearius</i>	Boatbill heron	1

Scientific name	Common name	Number
Ciconiidae:		
<i>Dissoura episcopus</i>	Woolly-necked stork.....	1
<i>Ibis cinereus</i>	Malay stork.....	2
<i>Jabiru mycteria</i>	Jabiru.....	3
<i>Leptoptilus crumeniferus</i>	Marabou.....	1
<i>Leptoptilus dubius</i>	Indian adjutant.....	1
<i>Leptoptilus javanicus</i>	Lesser adjutant.....	2
<i>Mycteria americana</i>	Wood ibis.....	1
Threskiornithidae:		
<i>Ajaia ajaia</i>	Roseate spoonbill.....	4
<i>Guara alba</i>	White ibis.....	8
<i>Guara alba</i> × <i>G. rubra</i>	Hybrid white and scarlet ibis.....	1
<i>Guara rubra</i>	Scarlet ibis.....	1
<i>Threskiornis melanocephala</i>	Black-headed ibis.....	4
<i>Threskiornis spinicollis</i>	Straw-necked ibis.....	2
Phoenicopteridae:		
<i>Phoenicopterus chilensis</i>	Chilean flamingo.....	2
<i>Phoenicopterus ruber</i>	Cuban flamingo.....	1
ANSERIFORMES		
Anhimidae:		
<i>Chauna chavaria</i>	White-cheeked screamer.....	1
<i>Chauna torquata</i>	Crested screamer.....	7
Anatidae:		
<i>Aix sponsa</i>	Wood duck.....	8
<i>Anas bahamensis</i>	Bahama pintail.....	2
<i>Anas domestica</i>	Pekin duck.....	51
<i>Anas domestica</i> × <i>A. platyrhynchos</i>	Pekin duck × mallard duck hybrid.....	1
<i>Anas platyrhynchos</i>	Mallard duck.....	57
<i>Anas rubripes</i>	Black duck.....	6
<i>Anser albifrons</i>	American white-fronted goose.....	1
<i>Anser cinereus domestica</i>	Toulouse goose.....	2
<i>Anseranus semipalmata</i>	Australian pied goose.....	2
<i>Branta canadensis</i>	Canada goose.....	20
<i>Branta canadensis occidentalis</i>	White-cheeked goose.....	24
<i>Branta canadensis</i> × <i>Chen caerulescens</i>	Hybrid Canada goose × blue goose.....	2
<i>Branta hutchinsii</i>	Hutchin's goose.....	4
<i>Branta hutchinsii minima</i>	Cackling goose.....	6
<i>Cairina moschata</i>	Muscovy duck.....	12
<i>Cereopsis novaehollandiae</i>	Cape Barren goose.....	1
<i>Chen allantica</i>	Snow goose.....	4
<i>Chen caerulescens</i>	Blue goose.....	3
<i>Chenopsis atrata</i>	Black swan.....	12
<i>Chloephaga leucoptera</i>	Magellan goose.....	1
<i>Coscoroba coscoroba</i>	Coscoroba.....	2
<i>Cygnopsis cygnoides</i>	Domestic goose.....	1
<i>Cygnus columbianus</i>	Whistling swan.....	2
<i>Cygnus melanocoryphus</i>	Black-necked swan.....	1
<i>Cygnus olor</i>	Mute swan.....	2
<i>Dafila acuta</i>	Pintail.....	10

Scientific name	Common name	Number
Anatidae—Continued		
<i>Dafila spinicauda</i>	Chilean pintail.....	1
<i>Dendrocygna arborea</i>	Black-billed tree duck.....	3
<i>Dendrocygna viduata</i>	White-faced tree duck.....	2
<i>Dendronessa galericulata</i>	Mandarin duck.....	4
<i>Mareca americana</i>	Baldpate.....	1
<i>Marila affinis</i>	Lesser scaup.....	1
<i>Marila collaris</i>	Ring-necked duck.....	2
<i>Metopiana peposaca</i>	Rosy-billed pouchard.....	3
<i>Nettion carolinense</i>	Green-winged teal.....	2
<i>Nettion formosum</i>	Baikal teal.....	3
<i>Nyroca</i> sp.....	Hybrid duck.....	1
<i>Nyroca valisineria</i>	Canvasback duck.....	1
<i>Philacte canagica</i>	Emperor goose.....	2
<i>Querquedula discors</i>	Blue-winged teal.....	2
FALCONIFORMES		
Cathartidae:		
<i>Cathartes aura</i>	Turkey vulture.....	1
<i>Coragyps atratus</i>	Black vulture.....	3
<i>Sarcoramphus papa</i>	King vulture.....	2
<i>Vultur gryphus</i>	Andean condor.....	1
Sagittariidae:		
<i>Sagittarius serpentarius</i>	Secretary bird.....	2
Accipitridae:		
<i>Accipiter striatus velox</i>	Sharp-shinned hawk.....	1
<i>Buteo jamaicensis</i>	Red-tailed hawk.....	6
<i>Buteo lineatus elegans</i>	Southern red-shouldered hawk.....	1
<i>Buteo lineatus lineatus</i>	Red-shouldered hawk.....	3
<i>Buteo melanoleucus</i>	South American buzzard eagle.....	2
<i>Buteo platypterus</i>	Broad-winged hawk.....	1
<i>Buteo poecilochrous</i>	Red-backed buzzard.....	2
<i>Buteo swainsoni</i>	Swainson's hawk.....	1
<i>Gypohierax angolensis</i>	Fish-eating vulture.....	1
<i>Gyps fulvus</i>	Griffon vulture.....	1
<i>Gyps rueppelli</i>	Ruppell's vulture.....	2
<i>Haliaeetus leucocephalus</i>	Bald eagle.....	5
<i>Haliastur indus</i>	Brahminy kite.....	5
<i>Harpia harpya</i>	Harpy eagle.....	2
<i>Milvago chimango</i>	Chimango.....	3
<i>Milvus migrans parasitus</i>	African yellow-billed kite.....	2
<i>Pandion haliaetus carolinensis</i>	Osprey or fish hawk.....	1
<i>Parabuteo unicinctus</i>	One-banded hawk.....	1
<i>Sarcogyps calvus</i>	Indian Pondicherry vulture.....	1
<i>Spiziastur melanoleucus</i>	Black and white hawk eagle.....	1
<i>Torgos tracheliotus</i>	African eared vulture.....	1
Falconidae:		
<i>Daptrius americanus</i>	Red-throated caracara.....	3
<i>Falco mexicanus</i>	Prairie falcon.....	1
<i>Falco peregrinus anatum</i>	Duck hawk.....	1
<i>Falco sparverius</i>	Sparrow hawk.....	11
<i>Falco sparverius interaediis</i>	South American sparrow hawk.....	1
<i>Polyborus plancus</i>	South American caracara.....	1

GALLIFORMES

Scientific name	Common name	Number
Cracidae:		
<i>Craz fasciolata</i>	Crested curassow.....	2
<i>Craz rubra</i>	Panama curassow.....	1
<i>Mitu mitu</i>	Razor-billed curassow.....	2
Phasianidae:		
<i>Argusianus argus</i>	Argus pheasant.....	2
<i>Catreus wallichii</i>	Cheer pheasant.....	1
<i>Chrysolophus amherstiae</i>	Lady Amherst's pheasant.....	1
<i>Chrysolophus pictus</i>	Golden pheasant.....	4
<i>Colinus cristatus</i>	Crested quail.....	1
<i>Crossoptilon auritum</i>	Blue-eared pheasant.....	1
<i>Gallus</i> sp.....	Bantam chicken.....	4
<i>Gallus</i> sp.....	Game fowl.....	8
<i>Gallus</i> sp.....	Oriental silky bantam fowl.....	6
<i>Gallus</i> sp.....	Fighting fowl.....	8
<i>Gallus</i> sp.....	Long-tailed fowl.....	1
<i>Gallus gallus</i>	Red jungle fowl.....	9
<i>Gallus gallus</i> hybrid.....	Hybrid red jungle fowl × bantam fowl.....	4
<i>Gallus lafayetii</i>	Ceylonese jungle fowl.....	1
<i>Gallus sonneratii</i>	Gray jungle fowl.....	1
<i>Gennaeus albocristatus</i>	White-crested kaleege.....	2
<i>Gennaeus leucomelanus</i>	Nepal kaleege.....	2
<i>Gennaeus nycthemerus</i>	Silver pheasant.....	3
<i>Hierophasis swinhoii</i>	Swinhoe's pheasant.....	2
<i>Lophophorus impeyanus</i>	Himalayan impeyan pheasant.....	1
<i>Pavo cristatus</i>	Peafowl.....	8
<i>Phasianus torquatus</i>	Ring-necked pheasant.....	3
<i>Polyplectron napoleonis</i>	Palawan peacock pheasant.....	1
<i>Syrnaticus reevesi</i>	Reeve's pheasant.....	2
Numididae:		
<i>Acryllium vulturinum</i>	Vulturine guinea fowl.....	1
<i>Numida</i> sp.....	Guinea fowl.....	2
Meleagrididae:		
<i>Agriocharis ocellata</i>	Ocellated turkey.....	4
<i>Meleagris gallopavo</i>	Wild turkey.....	2
<i>Meleagris gallopavo</i> var.....	Domestic turkey.....	1
GRUIFORMES		
Gruidae:		
<i>Anthropoides virgo</i>	Demoiselle crane.....	2
<i>Balearica pavonina</i>	West African crowned crane.....	2
<i>Balearica regulorum gibbericeps</i>	East African crowned crane.....	1
<i>Grus leucauchen</i>	White-naped crane.....	1
<i>Grus leucogeranus</i>	Siberian crane.....	2
Psophiidae:		
<i>Psophia leucoptera</i>	White-backed trumpeter.....	2
Rallidae:		
<i>Amaurornis phoenicurus</i>	White-breasted rail.....	1
<i>Aramides cajanea</i>	Wood rail.....	2
<i>Fulica americana</i>	American coot.....	14
<i>Gallinula chloropus cachinnans</i>	Florida gallinule.....	
<i>Gallinula chloropus orientalis</i>	Sumatran gallinule.....	1
<i>Porphyrio poliocephalus</i>	Gray-headed porphyrio.....	23

Scientific name	Common name	Number
Cariamidae:		
<i>Cariama cristata</i>	Cariama or seriema.....	2
CHARADRIIFORMES		
Burhinidae:		
<i>Burhinus bistriatus</i>	South American thick-knee....	2
Haematopodidae:		
<i>Haematopus ostralegus</i>	European oyster catcher.....	1
Charadriidae:		
<i>Belanopterus chilensis</i>	Chilean lapwing.....	2
Laridae:		
<i>Larus argentatus</i>	Herring gull.....	2
<i>Larus delawarensis</i>	Ring-billed gull.....	1
<i>Larus dominicanus</i>	Kelp gull.....	2
<i>Larus novae-hollandiae</i>	Silver gull.....	7
Glareolidae:		
<i>Glareola pratincola</i>	Collared pratincole.....	1
COLUMBIFORMES		
Columbidae:		
<i>Columba livia</i>	Domestic pigeon.....	12
<i>Ducula aenea</i>	Green imperial pigeon.....	1
<i>Gallicolumba luzonica</i>	Bleeding-heart dove.....	1
<i>Gallicolumba luzonica</i> × <i>Turtur risorius</i>	Bleeding-heart dove × ring-necked dove hybrid.....	2
<i>Geopelia cuneata</i>	Diamond dove.....	1
<i>Goura victoria</i>	Victoria crowned pigeon.....	1
<i>Leptotila rufaxilla</i>	Scaled pigeon.....	1
<i>Muscadivores paulina</i>	Celebian imperial pigeon.....	1
<i>Streptopelia chinensis</i>	Asiatic collared dove.....	2
<i>Streptopelia chinensis ceylonensis</i>	Lace-necked or ash dove.....	1
<i>Streptopelia tranquebarica</i>	Blue-headed ring dove.....	2
<i>Turtur risorius</i>	Ring-necked dove.....	35
<i>Zenaida auriculata</i>	South America mourning dove..	3
PSITTACIFORMES		
Psittacidae:		
<i>Agapornis lilianae</i>	Peach-faced love bird.....	3
<i>Amazona aestiva</i>	Blue-fronted parrot.....	1
<i>Amazona auropalliata</i>	Yellow-naped parrot.....	3
<i>Amazona ochrocephala</i>	Yellow-headed parrot.....	3
<i>Amazona oratrix</i>	Double yellow-headed parrot..	5
<i>Anodorhynchus hyacinthinus</i>	Hyacinthine macaw.....	1
<i>Ara ararauna</i>	Yellow and blue macaw.....	2
<i>Ara macao</i>	Red, blue, and yellow macaw..	1
<i>Aratinga euops</i>	Cuban conure.....	1
<i>Aratinga pertinax</i>	Gray-headed conure.....	1
<i>Calyptorhynchus magnificus</i>	Banksian cockatoo.....	1
<i>Coracopsis nigra</i>	Lesser vasa parrot.....	1
<i>Cyanopsittacus spixi</i>	Spix's macaw.....	1
<i>Ducorpsis sanguineus</i>	Bare-eyed cockatoo.....	2
<i>Eclectus pectoralis</i>	Eclectus parrot.....	1
<i>Eolophus roseicapillus</i>	Roseate cockatoo.....	1
<i>Kakatoe alba</i>	White cockatoo.....	2

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Psittacidae—Continued		
<i>Kakatoe ducrops</i>	Solomon Islands cockatoo.....	2
<i>Kakatoe galerita</i>	Large sulphur-crested cockatoo.....	3
<i>Kakatoe leadbeateri</i>	Leadbeater's cockatoo.....	1
<i>Kakatoe moluccensis</i>	Great red-crested cockatoo.....	1
<i>Kakatoe sulphurea</i>	Lesser sulphur-crested cockatoo.....	1
<i>Lorius domicella</i>	Rajah lory.....	2
<i>Lorius garrulus</i>	Red lory.....	1
<i>Melopsittacus undulatus</i>	Grass paroquet.....	34
<i>Myopsitta monachus</i>	Quaker paroquet.....	1
<i>Nestor notabilis</i>	Kea.....	1
<i>Nymphicus hollandicus</i>	Cockatiel.....	2
<i>Pionites xanthomeria</i>	Amazonian caique.....	1
<i>Psittacula eupatria</i>	Red-shouldered paroquet.....	1
<i>Psittacula krameri</i>	Kramer's paroquet.....	1
<i>Psittacula longicauda</i>	Long-tailed paroquet.....	1
CUCULIFORMES		
Cuculidae:		
<i>Eudynamis scolopaceus</i>	Koel.....	1
STRIGIFORMES		
Tytonidae:		
<i>Tyto alba pratincola</i>	Barn owl.....	6
Strigidae:		
<i>Bubo virginianus</i>	Great horned owl.....	9
<i>Ketupa ketupa</i>	Malay fish owl.....	1
<i>Nyctea nyctea</i>	Snowy owl.....	1
<i>Otus asio</i>	Screech owl.....	2
<i>Strix varia varia</i>	Barred owl.....	6
TROGONIFORMES		
Trogonidae:		
<i>Pharomachrus mocino</i>	Quetzal.....	6
CORACIIFORMES		
Alcedinidae:		
<i>Dacelo gigas</i>	Kookaburra.....	2
<i>Halcyon sanctus</i>	Sacred kingfisher.....	1
Coraciidae:		
<i>Anthraceros coronatus</i>	Pied hornbill.....	2
<i>Tockus birostris</i>	Gray hornbill.....	2
Momotidae:		
<i>Momotus lessoni</i>	Motmot.....	1
PICIFORMES		
Ramphastidae:		
<i>Aulacorhynchus sulcatus sulcatus</i>	Groove-billed toucanet.....	1
<i>Pteroglossus aracari</i>	Black-necked aracari.....	2
<i>Pteroglossus torquatus</i>	Aracari toucan.....	1
<i>Ramphastos carinatus</i>	Sulphur-breasted toucan.....	2
<i>Ramphastos piscivorus</i>	Toco toucan.....	1

PASSERIFORMES

Scientific name	Common name	Number
Cotingidae:		
<i>Rupicola rupicola</i>	Cock-of-the-rock.....	2
Pittidae:		
<i>Pitta moluccensis</i>	Molucca pitta.....	2
Corvidae:		
<i>Callocitta formosa</i>	Mexican jay.....	1
<i>Cissa chinensis</i>	Chinese cissa.....	2
<i>Cissilopha yucatanica</i>	Yucatan blue jay.....	4
<i>Corvus albus</i>	White-breasted crow.....	2
<i>Corvus brachyrhynchos</i>	American crow.....	3
<i>Corvus corax principalis</i>	Northern raven.....	2
<i>Corvus cornix</i>	Hooded crow.....	1
<i>Corvus cryptoleucus</i>	White-necked raven.....	1
<i>Corvus insoleus</i>	Indian crow.....	2
<i>Cyanocitta cristata</i>	Blue jay.....	2
<i>Cyanocorax chrysops</i>	Urraca jay.....	1
<i>Cyanopica cyana</i>	Azure-winged pie.....	1
<i>Dendrocitta vagabunda</i>	Rufus tree pie.....	2
<i>Garrulus lanceolatus</i>	Black-throated jay.....	1
<i>Gymnorhina hypoleuca</i>	White-backed piping crow.....	1
<i>Pica pica hudsonica</i>	American magpie.....	3
<i>Urocissa caerulea</i>	Formosan red-billed pie.....	2
<i>Urocissa occipitalis</i>	Red-billed blue magpie.....	1
Paradisaeidae:		
<i>Ailuroedus crassirostris</i>	Australian catbird.....	1
<i>Ptilonorhynchus violaceus</i>	Satin bowerbird.....	1
Timaliidae:		
<i>Garrulax albicularis</i>	Asiatic laughing thrush.....	2
<i>Garrulax bicolor</i>	White-headed laughing thrush.....	2
<i>Garrulax pectoralis picticollis</i>	Chinese collared laughing thrush.....	1
Pycnonotidae:		
<i>Pycnonotus analis</i>	Yellow-vented bulbul.....	1
Mimidae:		
<i>Melanotis caerulescens</i>	Blue catbird.....	1
<i>Mimus polyglottos leucopterus</i>	Western mockingbird.....	1
Turdidae:		
<i>Platycichla flavipes</i>	Yellow-footed thrush.....	1
<i>Turdus grayi</i>	Bonaparte's thrush.....	1
<i>Turdus migratorius</i>	Eastern robin.....	2
<i>Turdus rufiventris</i>	Argentine robin.....	1
Sturnidae:		
<i>Galeopsar salvadorii</i>	Crested starling.....	1
<i>Gracula religiosa</i>	Hill mynah.....	1
<i>Graculipica melanoptera</i>	White starling.....	1
<i>Pastor roseus</i>	Rosy pastor.....	1
<i>Sturnia malabarica</i>	Pied mynah.....	2
<i>Sturnus vulgarus</i>	Starling.....	1

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Ploceidae:		
<i>Aidemosyne cantans</i>	Tawny waxbill.....	4
<i>Aidemosyne malabarica</i>	Indian silver-bill.....	2
<i>Aidemosyne modesta</i>	Plum-head finch.....	2
<i>Alisteranus cinctus</i>	Parson finch.....	2
<i>Amadina fasciata</i>	Cut-throat weaver finch.....	17
<i>Amandava mandava</i>	Strawberry finch.....	3
<i>Cayleya picta</i>	Painted finch.....	1
<i>Diatropura procne</i>	Giant whydah.....	2
<i>Estrilda</i> sp.....	Red-eared waxbill.....	8
<i>Estrilda cinerea</i>	Common waxbill.....	25
<i>Euplectes franciscana</i>	Bishop weaver.....	8
<i>Hypochera ultramarina</i>	Combasou or indigo bird.....	3
<i>Lagonosticta senegalla</i>	African fire finch.....	2
<i>Lonchura leucogastroides</i>	Bengalee finch.....	3
<i>Munia maja</i>	White-headed munia.....	2
<i>Munia malacca</i>	Black-throated munia.....	1
<i>Munia oryzivora</i>	Java sparrow.....	3
<i>Munia punctulata</i>	Spice finch.....	3
<i>Neopoephila personata</i>	Masked finch.....	2
<i>Ploceus baya</i>	Baya weaver.....	3
<i>Ploceus intermedius</i>	Black-cheeked weaver.....	2
<i>Ploceus vitellinus</i>	Vitelline masked weaver.....	7
<i>Poephila acuticauda</i>	Long-tailed finch.....	4
<i>Poephila gouldiae</i>	Gouldian finch.....	4
<i>Quelea quelea</i>	Red-billed weaver.....	5
<i>Quelea quelea lathami</i>	Southern masked weaver finch.....	2
<i>Sporaeginthus melopodus</i>	Orange-cheeked waxbill.....	60
<i>Steganura paradisea</i>	Paradise whydah.....	18
<i>Stictoptera bichenovii</i>	Binchenov's finch.....	2
<i>Taeniopygia castanotis</i>	Zebra finch.....	4
<i>Uraeginthus bengalus</i>	Cordon blue finch.....	60
Icteridae:		
<i>Agelaius assimilis</i>	Cuban red-winged blackbird.....	1
<i>Amblyramphus holosericeus</i>	Scarlet-headed blackbird.....	1
<i>Gymnomystax mexicanus</i>	Giant oriole.....	1
<i>Icterus bullocki</i>	Bullock's troupial.....	1
<i>Notiopsar curaeus</i>	Chilean blackbird.....	2
<i>Trupialis defilippi</i>	Military starling.....	4
<i>Xanthocephalus xanthocephalus</i>	Yellow-headed blackbird.....	2
Thraupidae:		
<i>Ramphocelus carbo</i>	Silver-beaked tanager.....	4
<i>Ramphocelus dimidiatus</i>	Crimson tanager.....	2
<i>Ramphocelus flammigerus</i>	Yellow tanager.....	5
<i>Ramphocelus passerini</i>	Passerini tanager.....	1
<i>Tanagra darwini</i>	Darwin's tanager.....	2
<i>Thraupis cana</i>	Blue tanager.....	3

Scientific name	Common name	Number
Fringillidae:		
<i>Carpodacus mexicanus</i>	Mexican house finch.....	4
<i>Cyanocompsa argentina</i>	Argentine blue grosbeak.....	2
<i>Diuca diuca</i>	Diuca finch.....	14
<i>Junco hyemalis</i>	Slate-colored junco.....	1
<i>Lophospingus pusillus</i>	Black-crested finch.....	2
<i>Melopyrrha nigra</i>	Cuban bullfinch.....	2
<i>Melospiza melodia</i>	Song sparrow.....	1
<i>Paroaria cucullata</i>	Brazilian cardinal.....	1
<i>Paroaria gularis nigro-genis</i>	Black-eared cardinal.....	3
<i>Passerella iliaca</i>	Fox sparrow.....	1
<i>Passerina amoena</i>	Lazuli bunting.....	1
<i>Passerina cyanea</i>	Indigo bunting.....	2
<i>Passerina leclancheri</i>	Leclancher's bunting.....	2
<i>Passerina versicolor</i>	Blue bunting.....	2
<i>Pheucticus aureoventris</i>	Black and yellow grosbeak.....	2
<i>Phrygilus alaudinos</i>	Chilean lark finch.....	1
<i>Phrygilus fruticeti</i>	Mourning finch.....	4
<i>Phrygilus gayi</i>	Gay's gray-headed finch.....	1
<i>Poospiza torquata</i>	Ringed warbling finch.....	2
<i>Richmondina cardinalis</i>	Cardinal.....	3
<i>Serinus canarius</i>	Canary.....	4
<i>Serinus canarius</i> × <i>Carduelis mexicana</i>	Canary × siskin hybrid.....	2
<i>Serinus icterus</i>	Green singing finch.....	3
<i>Sicalis flaveola</i>	Mysto finch.....	3
<i>Sicalis luteola</i>	Saffron finch.....	3
<i>Spinus uropygialis</i>	Chilean siskin.....	1
<i>Sporophila aurita</i>	Hick's seed-eater.....	1
<i>Sporophila gutturalis</i>	Yellow-billed seed-eater.....	2
<i>Sporophila melanocephala</i>	Black-headed seed-eater.....	2
<i>Tiaris olivacea</i>	Mexican grassquit.....	5
<i>Volatinia jacarini</i>	Blue-black grassquit.....	1
<i>Zonotrichia albicollis</i>	White-throated sparrow.....	4
<i>Zonotrichia capensis</i>	Chingolo.....	1

REPTILES

LORICATA

Crocodylidae:

<i>Alligator mississippiensis</i>	Alligator.....	28
<i>Alligator sinensis</i>	Chinese alligator.....	3
<i>Caiman latirostris</i>	Broad-snouted caiman.....	1
<i>Caiman sclerops</i>	Spectacled caiman.....	3
<i>Crocodylus cataphractus</i>	Narrow-nosed crocodile.....	1
<i>Crocodylus niloticus</i>	African crocodile.....	2
<i>Crocodylus palustris</i>	"Toad" crocodile.....	2
<i>Crocodylus porosus</i>	Salt-water crocodile.....	1
<i>Crocodylus rhombifer</i>	Cuban crocodile.....	1
<i>Osteolaemus tetraspis</i>	Broad-nosed crocodile.....	3

SAURIA

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Iguanidae:		
<i>Basiliscus vittatus</i>	Basilisk.....	7
<i>Phrynosoma brevirostre</i>	Northern horned lizard.....	1
<i>Phrynosoma cornutum</i>	Horned lizard.....	6
<i>Sceloporus undulatus</i>	Pine or fence lizard.....	6
Anguidae:		
<i>Ophisaurus ventralis</i>	Legless lizard or glass "snake".....	2
<i>Celestus sagraei</i>	Sagra's skink.....	1
Agamidae:		
<i>Uromastix acanthinurus</i>	North African spiny-tailed lizard.....	1
Helodermatidae:		
<i>Heloderma horridum</i>	Mexican beaded lizard.....	2
<i>Heloderma suspectum</i>	Gila monster.....	5
Teiidae:		
<i>Tupinambis nigropunctatus</i>	Black tegu.....	5
Scincidae:		
<i>Eumeces fasciatus</i>	Blue-tailed skink.....	2
<i>Tiliqua scincoides</i>	Blue-tongued lizard.....	2
Varanidae:		
<i>Varanus komodoensis</i>	Komodo dragon.....	1
<i>Varanus monitor</i>	Indian monitor.....	1
<i>Varanus salvator</i>	Sumatran monitor.....	3
Zonuridae:		
<i>Zonurus giganteus</i>	African spiny lizard.....	2

SERPENTES

Boidae:		
<i>Constrictor constrictor</i>	Boa constrictor.....	1
<i>Constrictor imperator</i>	Central American boa.....	8
<i>Epicrates cenchris</i>	Rainbow boa.....	13
<i>Epicrates crassus</i>	Salamanta.....	1
<i>Epicrates striatus</i>	Haitian boa.....	1
<i>Eunectes murinus</i>	Anaconda.....	1
<i>Python molurus</i>	Indian rock python.....	1
<i>Python regius</i>	Ball python.....	1
Colubridae:		
<i>Boiga blandingi</i>	Brown tree snake.....	1
<i>Diadophis punctatus</i>	Ring-necked snake.....	2
<i>Dinodon semicarinatum</i>	Akamatah.....	1
<i>Elaphe guttata</i>	Corn snake.....	2
<i>Elaphe obsoleta</i>	Pilot snake.....	5
<i>Elaphe quadrivittata</i>	Chicken snake.....	2
<i>Lampropeltis triangulum triangulum</i>	Milk snake or spotted adder.....	1
<i>Natrix</i> sp.....	Water snake.....	12
<i>Natrix piscator</i>	Water snake.....	1
<i>Natrix sipedon</i>	Banded water snake.....	8
<i>Opheodrys vernalis</i>	Green grass snake.....	1

Scientific name	Common name	Number
Colubridae—Continued		
<i>Oxybelis acuminatus</i>	Pike-head snake.....	2
<i>Pituophis catenifer</i>	Western bull snake.....	1
<i>Pituophis melanoleucus</i>	Bull snake.....	2
<i>Ptyas mucosus</i>	Indian rat snake.....	1
<i>Storeria dekayi</i>	De Kay's snake.....	4
<i>Thamnophis macrostemma</i>	Mexican garter snake.....	1
<i>Thamnophis ordinoides</i>	Western garter snake.....	3
<i>Thamnophis sauritus</i>	Ribbon snake.....	1
<i>Thamnophis sirtalis</i>	Garter snake.....	7
Elapidae:		
<i>Dendroaspis</i> sp.....	Black tree snake or black mamba.....	1
<i>Dendroaspis viridis</i>	Green mamba.....	4
<i>Micrurus fulvius</i>	Coral snake.....	1
<i>Naja melanoleuca</i>	West African cobra.....	3
Crotalidae:		
<i>Agkistrodon bilineatus</i>	Mexican moccasin.....	14
<i>Agkistrodon mokeson</i>	Copperhead snake.....	3
<i>Agkistrodon piscivorus</i>	Cottonmouth moccasin.....	6
<i>Crotalus atrox</i>	Texas diamond-backed rattlesnake.....	1
<i>Crotalus horridus</i>	Eastern diamond-backed rattlesnake.....	1
<i>Trimeresurus flavoviridis</i>	Habu viper.....	3
<i>Sistrurus catenatus catenatus</i>	Massasauga.....	7
<i>Sistrurus miliarius</i>	Pigmy rattlesnake.....	2
TESTUDINATA		
Chelydridae:		
<i>Batrachemys nasuta</i>	South American snake-necked turtle.....	4
<i>Hydraspis</i> sp.....	Cágado or South American snake-necked turtle.....	1
<i>Hydromedusa tectifera</i>	South American snake-necked turtle.....	18
<i>Platemys platycephala</i>	Flat-headed turtle.....	1
Pelomedusidae:		
<i>Podocnemis expansa</i>	South American river tortoise.....	1
Kinosternidae:		
<i>Kinosternon subrubrum</i>	Musk turtle.....	6
Chelydridae:		
<i>Chelydra serpentina</i>	Snapping turtle.....	8
<i>Macrochelys temminckii</i>	Alligator snapping turtle.....	1
Testudinidae:		
<i>Chrysemys picta</i>	Painted turtle.....	7
<i>Clemmys guttata</i>	Spotted turtle.....	6
<i>Clemmys insculpta</i>	Wood turtle.....	3
<i>Cyclemys amboinensis</i>	Kura kura box turtle.....	1
<i>Graptemys barbouri</i>	Barbour's turtle.....	6
<i>Malaclemys centrata</i>	Diamond-back turtle.....	8
<i>Pelomedusa galeata</i>	Common African water tortoise.....	1

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Testudinidae—Continued		
<i>Pseudemys concinna</i>	Cooter.....	1
<i>Pseudemys rugosa</i>	Cuban terrapin.....	1
<i>Pseudemys scripta troostii</i>	{ Troost's turtle.....	1
	{ Troost's turtle (albino).....	2
<i>Pseudemys troostii</i>	Cumberland terrapin.....	4
<i>Terrapene carolina</i>	Box turtle.....	50
<i>Terrapene major</i>	Florida box turtle.....	4
<i>Testudo ephippium</i>	Duncan Island tortoise.....	2
<i>Testudo hoodensis</i>	Hood Island tortoise.....	2
<i>Testudo tabulata</i>	South American tortoise.....	1
<i>Testudo tornieri</i>	Soft-shelled land tortoise.....	1
<i>Testudo vicina</i>	Albemarle Island tortoise.....	5
Trionychidae:		
<i>Amyda ferox</i>	Soft-shelled turtle.....	6
<i>Amyda triunguis</i>	West African soft-shelled turtle.....	1

AMPHIBIA

CAUDATA

Salamandridae:		
<i>Triturus pyrrhogaster</i>	Red Japanese salamander....	77
<i>Triturus torosus</i>	Giant newt.....	2
<i>Triturus vulgaris</i>	Common European salamander.....	3
Ambystomidae:		
<i>Ambystoma lacustris</i>	Mexican axolotl.....	3
<i>Ambystoma opacum</i>	Marbled salamander.....	1
<i>Ambystoma tigrinum</i>	Axolotl.....	32
Cryptobranchidae:		
<i>Megalobatrachus japonicus</i>	Giant Japanese salamander....	2

SALIENTIA

Dendrobatidae:		
<i>Atelopus varius cruciger</i>	Yellow atelopus.....	34
<i>Dendrobates auratus</i>	Arrow-poison frog.....	160
<i>Dendrobates wittei</i>	Red and black frog.....	1
Bufonidae:		
<i>Bufo americanus</i>	Common toad.....	1
<i>Bufo empusus</i>	Sapo de concha.....	4
<i>Bufo marinus</i>	Marine toad.....	4
<i>Bufo peltacephalus</i>	Cuban giant toad.....	3
Ceratophryidae:		
<i>Ceratophrys ornata</i>	Horned frog.....	1
<i>Ceratophrys varius</i>	Horned frog.....	1
<i>Hyla</i> sp.....	Tree frog.....	1
<i>Hyla crucifer</i>	Tree frog.....	2
Pipidae:		
<i>Pipa pipa</i>	Surinam toad.....	6
<i>Xenopus laevis</i>	African clawed frog.....	12

Scientific name	Common name	Number
Ranidae:		
<i>Rana catesbeiana</i>	Bullfrog.....	2
<i>Rana clamitans</i>	Green frog.....	2
<i>Rana pipiens</i>	Leopard frog.....	10
<i>Rana sylvatica</i>	Wood frog.....	1

FISHES

<i>Anabas testudineus</i>	Climbing perch.....	5
<i>Anoptichthys jordani</i>	Blind characin.....	12
<i>Barbus everetti</i>	Clown barb.....	8
<i>Barbus partipentazona</i>	Banded barb.....	20
<i>Brachydanio rerio</i>	Zebra danio.....	3
<i>Carassius auratus</i>	Goldfish.....	10
<i>Channa asiatica</i>	Snakehead fish.....	2
<i>Cichlasoma festivum</i>	Flag cichlid.....	1
<i>Corydoras aeneus</i>	Trinidad catfish.....	5
<i>Danio malabaricus</i>	Blue danio.....	2
<i>Gymnocorymbus ternetzi</i>	Black tetra.....	4
<i>Helostoma temminckii</i>	Kissing gourami or gorami.....	2
<i>Hyphessobrycon innesi</i>	Neon tetra.....	3
<i>Kryptopterus bicirrhys</i>	Glass catfish.....	1
<i>Lebistes reticulatus</i>	Guppy.....	100
<i>Lepidosiren paradoxa</i>	South American lungfish.....	2
<i>Limis vittata</i>	Cuban limia.....	10
<i>Mollienisia sphenops</i>	Victory molly.....	12
<i>Monocirrhus polyacanthus</i>	Leaf fish.....	1
<i>Otocinclus affinis</i>	Sucker catfish.....	6
<i>Platypoecilus</i>	Red moon.....	3
<i>Pristella riddlei</i>	Tetra.....	10
<i>Protopterus annectens</i>	African lungfish.....	2
<i>Pterophyllum scalare</i>	Angel fish.....	1

ARACHNIDS

<i>Eurypelma</i> sp.....	Tarantula.....	1
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INSECTS

<i>Blabera</i> sp.....	Giant cockroach.....	100
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SUMMARY

Animals on hand July 1, 1946.....	2, 553
Accessions during the year.....	1, 462

Total number of animals in collection during the year.....	4, 015
Removals for various reasons such as death, exchanges, return of animals on deposit, etc.....	1, 008

In collection on June 30, 1947..... 3, 007

Among the important losses of the year were three emperor penguins. Two of them had lived here for 5 years and 11 months; the last

one to die, for 6 years and 3 months. These, of course, are outstanding records for life in captivity for these interesting birds, but the loss was a heavy one.

STATUS OF COLLECTION

Class	Species	Indi-vid-uals	Class	Species	Indi-vid-uals
Mammals.....	189	609	Fish.....	24	316
Birds.....	336	1,235	Insects.....	1	100
Reptiles.....	94	380	Arachnids.....	1	1
Amphibians.....	24	365	Total.....	669	3,007

Respectfully submitted.

W. M. MANN, *Director.*

Dr. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 8

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the operations of the Astrophysical Observatory for the fiscal year ended June 30, 1947:

The Observatory has two divisions: (1) The original Division of Astrophysical Research, engaged primarily in a study of solar radiation, and (2) the more recently established Division of Radiation and Organisms, engaged in a study of the effects of radiation on organisms.

Both divisions of the Observatory helped to celebrate the one-hundredth anniversary of the founding of the Smithsonian Institution by participating in a special exhibit illustrating the activities of the Institution. Mechanical working models were displayed showing typical instruments as used by the Observatory at Camp Lee, Va., and also showing types of research in the Division of Radiation and Organisms, with emphasis placed on the role of light in the growth and development of plants.

(1) DIVISION OF ASTROPHYSICAL RESEARCH

Work in Washington.—As in the past, our first concern has been to appraise the solar-constant values received from our field stations and to plan and develop improvements in instrumental equipment and methods. Our plans have seemed unduly slow in fulfillment, but by way of anticipation we may state that in the near future at one of our field stations we expect to try several innovations. These include an improved vacuum bolometer, a fused quartz prism, and aluminized mirrors in the optical path in place of stellite. The resulting large increase in ultraviolet deflections should permit a more accurate study of the day-to-day changes in this important region.

Our second concern has been the work at Camp Lee, Va., under contract with the Office of the Quartermaster General, described in last year's report. The records of the Camp Lee measurements of sun and sky radiation have been compiled and prepared for publication in a series of 11 reports to the Quartermaster General. The maintenance of the equipment and observations at Camp Lee, and the preparation of the reports have all been under the direction of William H. Hoover. With the close of the fiscal year we have completed 18 months of con-

tinuous observations at Camp Lee. These records give the sun and sky radiation in calories per square centimeter, for each hour of each day divided as follows:

- (1) Total intensity on a horizontal surface.
- (2) Total intensity on a surface inclined 45° to the east.
- (3) Ultraviolet intensity on a surface 45° to the east.
- (4) Visible intensity 45° to the east.
- (5) Infrared intensity 45° to the east.
- (6) Intensity under a vycor filter which transmits all radiation, inclined 45° to the south.
- (7) Intensity under a black filter (Corning 2540) which cuts off the ultraviolet and visible, and transmits the infrared, 45° to the south.
- (8) Intensity under a yellow filter (Corning 3385) which cuts off the ultraviolet and transmits the visible and infrared, 45° to the south.
- (9) Ultraviolet intensity on a horizontal surface measured with a special photoelectric ultraviolet meter.

The measurement and reduction of these voluminous records have been tedious and time-consuming. Integrating devices which will greatly simplify the work are being studied by Mr. Hoover and L. B. Clark, and several such devices are under construction in our shops.

It is now 13 years since Dr. C. G. Abbot and the Director last determined the standard scale of solar radiation on Mount Wilson. In anticipation of a new determination of this scale in the near future, the double-barreled water-flow pyrheliometer used successfully in 1934 has been partially rebuilt. Rubber joints within the instrument have been eliminated, copper-constantan thermojunctions replace the former nickel-platinum junctions, and the thermoelement arrangement is made more simple and efficient.

Dr. Abbot, research associate of the Observatory, has continued his studies of the effects of solar changes on weather. He has also experimented with a small solar engine, and has made preparations for a further study of the energy spectra of stars which he will undertake soon with the aid of the Mount Wilson 100-inch telescope.

At the request of Dr. Henryk Arctowski, and with the cooperation of Dr. Abbot and the Secretary of the Institution, Dr. Alexander Wetmore, arrangements were made for John McLean Hildt to come to Washington to assist Dr. Arctowski for 1 year. Mr. Hildt, formerly meteorologist for the American Overseas Airlines, began work with Dr. Arctowski on June 2, 1947. He will help organize and prepare for publication the large amount of material which Dr. Arctowski has accumulated.

Work in the field.—In October 1946 Mr. Hoover and Paul Greeley went to New Mexico and packed for shipment the entire equipment of our Tyrone station, closed since February 1946. Arrangements were made for the sale and disposal of the buildings and for the return

of the site to the custody of the Forest Service. The equipment was sent to Miami, Fla., and stored pending the completion of a building suitable for temporary solar observations at this sea-level location.

In further development of their studies of the causes of tent deterioration, the Quartermaster Department decided to extend the Camp Lee work to include measurements and exposures at a wet, sea-level station and also at a dry, high-altitude station. Fortunately, in Miami, Fla., the General Motors Corp. maintains a test field for the exposure and testing of various materials. At the suggestion of Dr. S. J. Kennedy, of the Military Planning Division, Office of the Quartermaster General, a cooperative program was arranged between the General Motors Corp., the Quartermaster Department, and the Smithsonian Institution. General Motors generously undertook to build a special observing shelter at their test field, to house our spectrobolometric equipment formerly in operation at Tyrone, N. Mex. This building, a most satisfactory, well-insulated structure of cement brick, was completed in April 1947. On May 1 F. A. Greeley, recently director at our Montezuma, Chile, station, took charge of the installation of our equipment. Spectrobolometric observations are planned for a period of 1 year.

During the war years our field stations were unavoidably unmanned. It is therefore a satisfaction to state that each of the stations now has two competent observers, as in prewar days.

During the fiscal year, a generous gift to further the work of the Division was received from John A. Roebeling. The staff of the Observatory is sincerely grateful to Mr. Roebeling, and to Dr. Abbot through whose kindly interest the gift was received.

(2) DIVISION OF RADIATION AND ORGANISMS

(Report prepared by Earl S. Johnston, Chief of the Division)

General.—Members of the Division were consulted as usual by outside individuals and organizations regarding problems arising in the field of radiation, its measurement and its effect on living matter. Individual members also participated actively in the affairs of national and local scientific organizations.

Research.—During the year the research of the Division of Radiation and Organisms was concentrated under two projects: (1) Photosynthesis, and (2) plant growth and development as influenced by light.

(1) *Photosynthesis.*—The purpose of this project is to determine the role of light, especially the wave-length effects, on the fixation of carbon by green plants. Included in this project are studies (*a*) to determine a more complete photosynthesis-action spectrum by use of the special spectrographic method for the determination of carbon

dioxide as developed in this laboratory; (b) to determine chlorophyll formation in the different regions of the spectrum; (c) to investigate the wave-length balance associated with optimum plant production

Many instrumental problems have arisen in connection with this CO₂-measuring method which have prevented the full use of the apparatus in many of the planned experiments. New heat exchangers have been installed for better temperature control and other improvements made. After making 67 test runs, each of which required from 5 to 6 hours, all but two of the problems have been overcome.

The Division has recently obtained a suitable spectrophotometer with which to continue its studies on chlorophyll formation. Work in the study of wave-length balance and optimum plant growth has been continued.

(2) *Plant growth and development as influenced by light.*—The purposes of this project are (a) to determine the mechanism of dormancy in light-sensitive seeds, and (b) to study developmental physiology of grass seedlings.

Role of light in seed germination.—It has long been known that germination of many species of seeds under certain conditions is very markedly stimulated by, or entirely dependent upon, irradiation. About 10 years ago a cooperative investigation carried out in this laboratory (Flint and McAlister) demonstrated that only certain portions of the spectrum are stimulatory to germination whereas other regions are inhibitory. The mechanism of these effects of light has remained completely obscure, however.

Subsequent discoveries by other workers have suggested new experimental approaches to this problem which has been taken up again. These discoveries are (1) that certain chemicals have the ability to evoke germination in darkness and thus appear to act as substitutes for light, and (2) that other chemicals act as germination inhibitors in darkness but that light tends to overcome the inhibitory action.

A considerable variety of compounds has been tested for ability to promote germination of lettuce seeds in darkness at temperatures which, in the absence of specific stimulations, permit germination only in light. A number of active substances have been found. The tests are being continued in an attempt to correlate the physiological potency with molecular architecture.

The light-sensitive inhibitory effect produced by coumarin does not appear to be specific, being exhibited also by several other compounds among the many which have been examined. Thus there is little support for the suggestion made by other workers that coumarin, or a chemically closely related substance, is responsible for the natural light-sensitivity of lettuce seed. A report of this work is now being prepared for publication.

Evidence has been obtained, however, that dormancy and germination in this species is regulated, or at least influenced by an endogenous inhibitory substance. The nature of this inhibitor and the mode of its action are being studied.

A critical review of the literature dealing with germination of lettuce is also in preparation.

Effect of light on development of grass seedlings. Various phases of this project have been carried forward as time permitted. A comparative investigation of the action spectrum for inhibition of mesocotyl growth in several species has been published. Tests on the influence of several seed-disinfection treatments on subsequent seedling development have been completed. Additional experiments have been made on the effects of various salts on growth of etiolated oats. In order to explain the observed gross morphological effects of light and other environmental factors on mesocotyl elongation, a histological study of this organ is in progress. A large number of slides have been prepared and are being examined. It is planned to resume the experiments on the interrelation between light and temperature as affecting coleoptile and root growth as soon as the necessary equipment, now being constructed, is available.

Volatile plant-growth inhibitors. It was observed that in a wooden growth chamber, of which the interior had been varnished, the germination of several species of seeds was completely checked or greatly retarded, although all the commonly recognized environmental conditions were favorable for development. On removal from this chamber normal development was resumed promptly. As the plants were not in direct contact with the original box it appeared that a volatile substance of great physiological activity was present. A large number of subsequent tests showed that volatile inhibitors are indeed produced, presumably as the result of oxidation processes, by films of varnishes, drying oils, unsaturated fat acids, and by several species of wood. The rapid and complete reversibility of the inhibition is especially remarkable. An agent with these properties might conceivably be of considerable value both in plant physiological experimentation and in practical plant culture. Studies on the identity of the responsible substance, or substances, are in progress.

PUBLICATIONS

The following publications relating to the work of the Observatory were issued during the year:

ABBOT, C. G., 1946-47 report on the 27.0074-day cycle in Washington precipitation. Smithsonian Misc. Coll., vol. 107, No. 3, March 1947.

ABBOT, C. G., The earth and the stars. D. Van Nostrand Co., Inc., New York. 1946. 288 pp.

ABBOT, C. G., The sun's short regular variation and its large effect on terrestrial temperatures. Smithsonian Misc. Coll., vol. 107, No. 4, April 1947.

ABBOT, C. G., Astrophysical contributions of the Smithsonian Institution. *Science*, vol. 104, No. 2693, August 1946.

ALDRICH, L. B., and associates, Reports on Camp Lee studies, submitted to the Office of the Quartermaster General, as follows:

Textile Series, Office of Quartermaster General, Report 17, Tent Research Report 3, pp. 53-99.

Reports 2 to 11, Smithsonian Institution to Office of Quartermaster General.

JOHNSTON, EARL S., The Division of Radiation and Organisms: Its origin and scope. *Scientific Monthly*, vol. 63, pp. 371-380, 1946.

JOHNSTON, EARL S., An establishment was established. *Journ. Washington Acad. Sciences*, vol. 37, pp. 37-40, 1947.

WEINTAUB, ROBERT L., and PRICE, LEONARD, Developmental physiology of the grass seedling. II. Inhibition of mesocotyl elongation in various grasses by red and by violet light. Smithsonian Misc. Coll., vol. 106, No. 21, May 1947.

Respectfully submitted.

L. B. ALDRICH, *Director*.

DR. A. WETMORE,

Secretary, Smithsonian Institution.

APPENDIX 9

REPORT ON THE NATIONAL AIR MUSEUM

SIR: On August 12, 1946, President Truman approved an act of the Seventy-ninth Congress (H. R. 5144) establishing, under the Smithsonian Institution, a bureau to be known as a National Air Museum. The act, now referred to as Public Law 722, stipulates that this bureau shall be administered by the Smithsonian Institution "with the advice of a board to be composed of the Commanding General of the Army Air Forces or his successor, the Chief of Naval Operations or his successor, the Secretary of the Smithsonian Institution, and two citizens of the United States appointed by the President from civilian life, who shall serve at the pleasure of the President."

The purpose of the National Air Museum is to "memorialize the national development of aviation; collect, preserve, and display aeronautical equipment of historical interest and significance; serve as a repository for scientific equipment and data pertaining to the development of aviation; and provide educational material for the historical study of aviation."

After the passage of the act, Dr. Wetmore discussed with General Spaatz and Admiral Nimitz the designation of appropriate representatives of the Army Air Forces and the Navy to the Advisory Board. As a result, General Spaatz appointed Maj. Gen. E. M. Powers, and Admiral Nimitz appointed Rear Adm. H. B. Sallada. The latter was replaced on May 1, 1947, by Rear Adm. A. M. Pride. On December 3, 1946, President Truman appointed Grover Loening and William B. Stout to be civilian members of the Advisory Board as provided in the law.

On December 16 the first and organizational meeting of the Advisory Board was held at the Smithsonian Institution in Washington. At this meeting Dr. Wetmore was unanimously elected chairman. A general discussion of the preliminary plans for an aeronautical museum then followed, the Board calling attention to the danger of losing valuable historical and technical material unless prompt action were taken. Toward this end, Dr. Wetmore was requested to communicate immediately with leaders in all branches of aeronautics requesting that such material be preserved for future review by the Board.

The Board also discussed section 3 of the act which calls on the Secretary of the Smithsonian Institution with the advice of the Ad-

visory Board "to investigate and survey suitable lands and buildings for selection as a site for a national air museum and to make recommendations to Congress for the acquisition of suitable lands and buildings for a national air museum."

At this meeting, too, the preparation of estimates of appropriations to implement the \$50,000 authorized by the Congress for the purposes of the act was discussed in detail, and Dr. Wetmore was advised by the Board to submit the request to the Bureau of the Budget. This was done, and on March 21, 1947, President Truman transmitted to Congress "A Supplemental Estimate of Appropriation for the Fiscal Year 1948 in the Amount of \$50,000 for the Smithsonian Institution" (H. R. Doc. No. 181). On April 30, 1947, Dr. Wetmore appeared before the Independent Offices Subcommittee on Appropriations and presented a brief statement on the origin of the National Air Museum and on the need for the requested appropriation.

Following this initial meeting of the Advisory Board, approximately 200 letters were addressed to aeronautical interests throughout the Nation. These letters called attention to the establishment of the National Air Museum and urged the recipients to advise the Board of any aeronautical items which in their estimation should be considered for inclusion in the future National Air Museum. The letter also requested that such materials be carefully preserved until such time as the Board could make a study of them. The response to these letters has been large and indicates the existence at this writing of much valuable museum material in private hands scattered throughout the Nation. Both the Army and Navy, too, are assembling and holding large quantities of valuable aeronautical material of the recent war years. A portion of these collections, and several private collections, were inspected toward the close of the year at the Institution's own expense.

The major problem involved in the advancement of the National Air Museum project is the acquisition of a storage depot for the temporary assembly of the museum material. This is most essential to prevent the permanent loss of material and to enable the Advisory Board to determine and recommend to Congress suitable lands and buildings for the new bureau. At the close of the year this vital problem was still unsolved, nor had the Congress appropriated the \$50,000 authorized and requested for use in the fiscal year 1948.

Respectfully submitted.

C. W. MITMAN,

Assistant to the Secretary for the National Air Museum.

DR. A. WETMORE,

Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON THE CANAL ZONE BIOLOGICAL AREA¹

SIR: It gives me pleasure to present herewith the annual report of the Canal Zone Biological Area, for the fiscal year ended June 30, 1947. As in past reports, there are included data regarding rainfall, temperatures, relative humidity, and other data which are invaluable to those coming to the island for study.

REGARDING THE ISLAND

As this is the first report published in several years, it is desirable to include here some of the data that appeared in the earlier Barro Colorado Island Biological Laboratory Reports—particularly so, because so many new readers will want this information.

The island was reserved for scientific purposes by Governor J. J. Morrow on April 17, 1923; hence in 1948 the island and its unique laboratory will celebrate its twenty-fifth anniversary. It is located in Gatun Lake, about halfway between Gamboa and Gatun. Its width is 3.1 miles, its length 3.4 miles, and its area 3,609.6 acres, or 5.64 square miles. Its coast line exceeds 25 miles. It is larger than the combined areas of the familiar islands of Taboga, Taboguilla, Urava, Otoque, Bona, Morro, Chamé, Estiva, Melones, Venado, Mandinga, Tabor, Ensená, Patterson, Tortola, Naos, Culebra, Perico, and Flamenco.

The shore line of Gatun Lake is on the average 85 feet above sea level, and the highest point on the island, 537 feet. There are 24 trails, marked off into 100-meter sections, so that not only are all parts of the island available with ease, but the 100-meter designations give it a sort of cross index; thus, for example, Wheeler-6 has a very definite location. And since all trails eventually lead to the main laboratory, no one has ever been known to be lost on the island.

As to buildings, there is a two-story main building 32 by 55 feet, the lower floor including a dining room, and the upper floor lodging rooms. There are two buildings 12 by 24 feet with two rooms each, the ZMA and Barbour Houses, the latter with a large porch for labora-

¹ This is the first report to be published since the Canal Zone Biological Area was placed under the administration of the Smithsonian Institution. The first to the sixteenth reports, for the years when the organization was known as the Barro Colorado Island Biological Laboratory, were issued in mimeograph form, the last in 1940. During the war, owing to military restrictions and other considerations, no reports were issued.

tory space. Then there is the Chapman House, also 12 by 24 feet, with a wide porch; the lower floor is screened in and serves as a splendid laboratory unit. The Eastman Kodak Co. has a building for its service, deterioration, and corrosion tests, the lower floor serving as workshop. There is a three-room library, and another building used by the Resident Manager. The upper part of the kitchen is used as a dormitory.

There are buildings at the end of the Barbour Trail, the Drayton Trail, the Pearson Trail, the Zetek Trail, and at Burrunga Point, all available for the use of scientists. At least two can live comfortably in these houses.

Inquiries should be addressed either to Dr. Alexander Wetmore, Secretary, Smithsonian Institution, Washington 25, D. C., or to James Zetek, Resident Manager, Drawer C, Balboa, C. Z. Accredited scientists receive an annual card pass on the railroad, and authority to purchase in the commissaries. Living conditions on the island are very comfortable, and working conditions good. Owing to the precautions taken, the malaria hazard is nil, and the water supply is safe.

As the island force looks after the dormitories and the meals, it means that the scientists are relieved of all housekeeping duties. Thus their entire time is available for their research problems. Those who have worked in the Tropics where such facilities are not available, where drinking water must be boiled and malaria precautions taken daily, know what it means to be relieved of these chores. Furthermore, in many tropical localities good medical facilities are not within easy reach, whereas on Barro Colorado Island the scientist is never more than an hour from a Panama Canal dispensary, or an hour and a half from Gorgas or Colon hospitals, where one finds the very best in medical or surgical services.

With rapid air mail and air express service the island is in very close touch with the United States, and being under the United States flag, it is almost like being in the States. On the other hand, the isolation provided by an island does away with the many distractions so common on the mainland.

THE ISLAND LITERATURE

Since the laboratory was established in 1923 as the Barro Colorado Island Biological Laboratory, there have appeared 603 individual published articles and books relating to studies made on the island. This is an enviable record, equaled by very few institutions of this sort. The field covered is vast, even including papers on studies made here on cosmic rays. Many of the papers on physiology have paved the way to other studies that have solved problems relative to certain human diseases. A 3- by 5-inch card record is kept of these individual

books and papers. One index is alphabetical by authors, the other by subjects.

The war halted the preparation and publication of many papers, as it also curtailed the number able to come to the laboratory for studies. During the war the laboratory was, of course, very active on problems relating to the war, particularly deterioration, corrosion, fungi, chemical problems, and related matters, but very few of these findings will appear in print. It is also known that papers have been published of which we have no record. It is a difficult task to cull all the literature, and probably the index is only 80 percent complete. Nevertheless, it is an amazing record.

SCIENTISTS AND THEIR STUDIES

Dr. T. C. SCHNEIRLA, curator of the department of animal behavior, American Museum of Natural History, perhaps the highest authority living on the behavior pattern of army ants, spent from February 7 to June 16, 1946, on the island, continuing his studies. A summary of his findings follows:

"These studies on army-ant behavior and its biological basis were begun on the island in 1932, and were continued in the rainy-season periods of 1933, 1936, and 1938. The work began as an attempt to analyze the complex behavior system of these ants as a case study of 'instinct,' but as it went along inevitably led into other special problems, such as the social organization of the army ants, and the relationship between reproductive processes and behavior.

"To investigate the last problem in particular a project was planned for 1942; however, the war interfered. Since all the preceding studies had been made in the rainy season, it was especially desirable to obtain evidence on the activities and adaptations of the *Ecitons* in the dry months. Plans for an intensive investigation under dry-season conditions were resumed in 1946.

"The basis of the study was the surveying of activities and conditions in two colonies, one of *Eciton hamatum* and one of *E. burchelli*, for as long a time as possible in the dry months. Other colonies of these two species were kept on record as far as possible for briefer periods, and supplementary field and laboratory tests were carried out on relevant problems. The object was to learn as much as possible about what changes may occur in the activities and in the brood production of these ants in the dry season.

"If there is any other situation in the world today where such a project involving correlated field and laboratory studies can be carried out advantageously, I have yet to learn of its existence. The results of this project illustrate the island's advantages. On the day of my arrival, February 7, I found a colony of *E. burchelli* bivouacked on

Shannon trail just beyond No. 2, and this colony was kept on record until just before departure on June 15—about 125 days in all. A colony of *E. hamatum*, found a few days later, was on record for nearly as long. Approximately 50 other colonies of these 2 species were studied more or less intensively during the 4 months.

"The findings, first of all, showed in convincing ways that the periodic behavior changes (regular alternation of nomadic and statary—i. e., sessile—colony behavior) that I have found invariable for these ants in the rainy season also hold through the dry season. Regular phases were found as follows: For *E. hamatum*, about 17 days nomadic and about 20 days statary in alternation; for *E. burchelli*, about 12 days nomadic and 21 days statary in alternation. An intensive study of colony brood-production, paralleling the behavior studies, revealed that in colonies which survive the dry season with their queens, new broods are produced at very regular intervals as in the rainy season. Further evidence was found that this regular brood-production, based of course upon a very regular delivery of successive batches of eggs by the queen, provides the causal basis for the described regularity of colony behavior. For example, the queens of *E. hamatum* produce new batches of eggs at about 36-day intervals. This island study of 1946 shows that this remarkable performance ordinarily is continuous throughout the year.

"The production of male individuals, it was found, occurs in the dry season, at times characteristic of the species. Evidently in colonies that produce males, only one brood of males per season is produced, otherwise the broods are immense worker broods as in the rainy season. The production of males was studied, from early larval stages to maturity and dissemination by flight. A brood of (about 3,000, as a rule) winged males requires about 3 weeks for its complete exodus through nightly flights, after emergence. Results indicate that most of the males that survive the flight reach other colonies (evidently through chancing upon and following raiding trails to the bivouacs). The flight evidently operates against adelphogamy, although some evidence was obtained for occasional returns of males into their colonies of origin. From this 1946 work a considerable part of the virtually unknown problem of Eciton mating can be sketched in. More of it, and especially how the wingless queens are produced, we hope to learn in 1947-48, when a project is planned for studying transitional conditions in the Ecitons from rainy to dry season months."

Dr. JAMES B. HAMILTON, professor of anatomy, Long Island College of Medicine, and one of the foremost authorities on hormones, initiated a most interesting and promising line of research dealing with the matter of baldness, a subject on which he has already published important papers. His experimental approach was through the three-

toed sloth, the male of which has on its back a prominent bald area or "tonsure." This sloth, and some of the large apes, appear to be the only animals that resemble man in that the adult males develop common baldness.

His observations thus far are in total agreement with the idea that a bald spot of increasing size develops upon sexual maturation of the male. It is still too early to report on his study of the anatomical material he obtained on the island. The sloths used were obtained through the cooperation of Mr. Shropshire and Lieutenant Keenan of the United States Army Sanitary Corps. If the studies corroborate the views outlined, then it will be important to study the pathogenesis of this condition. Its etiology is apparently identical with that responsible for other important pathological conditions, for example, hypertrophy and cancer of the prostate.

His present studies are only the beginnings of further ones. No one so far has made this approach through the sloth, and while quite a number of males and females received male hormone treatment, it is necessary to follow the experiment through on a large scale. This involves also a study of the sloths themselves, to learn how to keep them alive in captivity for at least 6 months. In captivity the sloth is not hardy, and no one as yet has made a serious study of the food habits and other characters of these animals. They are ideal for such studies.

R. J. KOWAL, entomologist in charge of the Gulfport, Miss., Laboratory of the Bureau of Entomology and Plant Quarantine, and Entomologists Samuel Dews and Harmon Johnston, of the same regional laboratory, began their studies about 4 years ago, upon the initiative of Kowal. The object was to obtain information on effective methods of preserving wood against deterioration due to termites and other organisms, as well as to rot. To quote Kowal: "The severity of conditions conducive to deterioration, and the excellent facilities for scientific study, make the island an ideal location for such investigations."

The studies began in 1943 when funds were made available through the United States Forest Service, and the Coordinator of Inter-American Affairs. Proposals for this work came as an outgrowth of requests for information from the Public Roads Administration, the War and Navy Departments, and other agencies engaged in the war effort. Briefly stated, the Inter-American Road became an urgent need, steel for bridges was hard to get and its transportation a problem, and to erect wood-preservation plants with creosote on the list of critical materials was out of the question. Could we not poison soils at the bridge abutments so as to eliminate the termite and rot hazard, and could we utilize native resistant trees by the additional process of sap-stream impregnation?

In the spring of 1943 two types of experiments were established, one to test the value of soil poisons in preventing damage by termites; the other to determine whether tropical tree species could be impregnated with water-soluble wood preservatives by the sap-stream method of impregnation. Soil poisoning had been previously tested on a small scale particularly in the treatment of soil along building foundations to prevent the entrance of termites into wood structure. The relative value of different soil poisons was not known, however, nor was information available on their effectiveness under tropical conditions. Thirty-nine different treatments were applied on Barro Colorado Island, each treatment being replicated 10 times. The procedure consisted of removing and treating 2 cubic feet of soil, replacing it, and driving a stake into the center of the treated area. After 3 years' exposure it was apparent that treatments by means of the so-called "saw-kerf banding" and bore-hole techniques were the most effective. In the case of several of the tree species, intake of the chemical was not satisfactory and preservation consequently was poor.

In 1946 the Division, in cooperation with the Corps of Engineers of the War Department, began investigations on problems of deterioration of wood and wood products confronting the Army. The studies deal mainly with problems under military conditions, and research is pointed toward development of practical methods of prevention and control which can be readily applied by the Army using materials immediately available on location. Several types of soil-poisoning tests were established on Barro Colorado Island in November 1946. An experiment similar to that described above was installed using numerous soil poisons and different dosages. Variations of the method were also tested, one being the surface application of chemicals and another the bore-hole method. A soil-poisoning experiment known as the "platform test" was also established. In this test poisons are applied to the soil surface by spraying or sprinkling, and the board or "platform" to be protected is laid on the treated area. Dosages in this test are considerably lighter than in tests described above. The experiment is designed with the object of developing a method of preventing damage to materials in storage dumps and similar installations.

The above experiments conducted in cooperation with the War Department comprise a total of approximately 100 treatments; all have been replicated 10 times.

Experiments on impregnation of seasoned wood with preservatives have been established in order to determine the methods and chemicals most satisfactory for the protection of wood from insect attack. The experiment, like those above, is designed to provide a reasonable degree of preservation by practical methods using chemicals readily

available to the Army on location. Ten different chemicals and chemical mixtures were used in the experiment. Stakes 12 inches long were treated by instant dip and by dips of 3 minutes, 1 hour and 12 hours. Ten replications were made of all treatments. All stakes were driven into the soil to a depth of 6 inches.

A small amount of treated fabrics, conduit, and insulation is now under test, and it is planned that more such material will be tested in the future. In addition, experiments will be conducted to develop methods and materials that might be of value in preventing attack of wood by marine organisms.

THEODORE J. MARTIN, technologist of the Forest Products Laboratory at Madison, Wis., made several trips to the island in connection with the installation and inspection of the various tests of plywoods, glues, paints, resins, and other materials. Since most of this is covered in the report of Mr. Middleswart, little need be added here.

It is always a great satisfaction to be able to give tribute where it is due. The thoroughness of Mr. Martin's work, his attention to details, his ability to see and appreciate what too many would not note, all were apparent during his work on the island.

MRS. ELIZABETH G. HARTMANN, of New York City, spent a short time on the island studying the bird life, preparatory to a more extended trip into Costa Rica. The abundance of life on the island, in addition to the birds, crowded each day with no end of new experiences and information and made her stay all too brief.

Dr. ALEXANDER WETMORE, Secretary, Smithsonian Institution, spent 2 days and 1 night, all he could spare on his return from Jacqué, and his urgent need to be back again in Washington. While all too brief, the period was spent in discussions with the Resident Manager of the island's more urgent needs.

G. E. ERIKSON, of the graduate school of Harvard University, spent some time on the island in connection with his research problems on the higher mammals.

C. C. SOPER, chemist for Eastman Kodak Co., and in charge of their research laboratory in Panama City, initiated and conducted on the island the most varied studies in connection with deterioration and corrosion of practically all the materials that enter into photography. The outcome of these studies means, of course, better results for those who do photographic work. Mr. Soper's investigations dealt not only with corrosion of lenses and its elimination, but also with the properties and keeping qualities of film, particularly color, papers, and other photographic supplies, and also with the matter of packing and packaging. It is the first really serious study of these multiple problems. The upper floor of the building built this year is used for these tests and studies.

Mr. Soper, through his knowledge of photography and photographic processes, has been extremely helpful to scientists on the island. It is hardly necessary to point out here the difficulties, as well as losses, incurred during the past war, because of the lack of previous studies of this nature. It is to the point to emphasize the soundness of the decision made to go to the humid Tropics to make these studies, rather than to depend on tests made in the continental United States by simulating conditions in the Tropics. It is possible to duplicate temperatures and humidities, but it is not possible to duplicate the often rapid changes, and certainly not the action of micro-organisms.

The past war has shown the wisdom as well as the urgency for conducting in the Tropics studies on corrosion, deterioration, packing and packaging, and similar problems, and particularly the need to study and test the great number of new materials which still lack sufficient service tests to show the true limits of their best usage.

Dr. GRAHAM BELL FAIRCHILD, medical entomologist to the Gorgas Memorial Laboratory, whose splendid work during the past war is so well known, made several brief visits to the island in connection with his entomological studies.

Dr. CHAS. F. QUAINANCE, spent a little over 8 months of his sabbatical leave on the Isthmus, a few months thereof on the island. As head of the biology department of Eastern Oregon College, his main objective was to learn as much as possible about the plants and animals of the Tropics, and particularly the environmental conditions. To supplement his notes and collections, he also took a great number of kodachrome photographs for use in his teaching.

It is one thing to read about the Tropics and then pass on this second-hand knowledge to students. But it is only when one sees, feels, hears, tastes, and smells that which is the humid Tropics that one is able to really teach about them. The past war emphasized the paucity of men who have had actual experience in the Tropics.

Dr. THOS. E. SNYDER, senior entomologist of the Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, and one of our greatest authorities on termites, came for a few weeks to discuss with the Resident Manager the extensive termite studies conducted on the island since 1923. The clearing of a piece of the immediate forest just behind the present laboratory buildings, to provide needed space for buildings and for water storage, necessitates the removal of several thousand of the termite exposure tests to a new area.

During his stay he examined all the trail-end buildings, which are also termite tests. A report on this is given elsewhere. The great value of the island for such tests and studies has been attested and emphasized so often that any repetition here becomes redundant.

Dr. GROVER C. PITTS, Naval Medical Research Institute at Bethesda, spent a very short period on the island because of difficulty in getting off in the midst of important research at that great Medical Center of the Navy. Hastily, he writes as follows:

"Let me review my objectives and results in visiting the island. By profession I am a physiologist with strong leanings toward natural history. Consequently, the purpose of my short visit was to gain some familiarity with a tropical fauna and flora and to explore the possibilities of making studies in comparative physiology there. A secondary object was to determine what the island might have to offer the Naval Medical Research Institute for purposes of field research. Though I am now out of the Navy, I continue my affiliation with NMRI as a civilian.

"Some results were obtained with regard to each objective. I identified and gained some familiarity with the following organisms, all new to me: 52 species of birds, 14 species of mammals, 5 species of reptiles, and an undetermined number of species of plants and invertebrates.

"This is at least some indication of what a worker can accomplish who desires to gain familiarity with the tropical biota and has only 1 week at his disposal.

"With regard to the opportunities for studies in comparative physiology, they are legion. More studies in temperature control of the type that Peter Morrison did are indicated. In the past I have done some work on diurnal rhythms in various physiological functions. The island with its many diurnal, nocturnal, and crepuscular creatures offers boundless material for this type of study. One would have to bring most of the specialized equipment needed, but the usual laboratory facilities are available. I hope to pursue one of these problems when time and finances provide the opportunity."

A. V. REGNIER, Jr., of Little Rock, Ark., visited the island for the purpose of preparing a motion picture of the wildlife, preparatory to a much longer stay later on. He exposed some 1,200 feet in color during the 3 weeks. He also included 2 weeks in Chiriquí, where he went in quest of the beautiful quetzal. Mr. Regnier reports:

"The finished film with titles and animated maps is about 900 feet in length. The sequence on the island opens with the launch coming in to the landing followed by a view of those arduous steps. Then in quick flashes, the mango, banana, coconut, lime, lemon, and orange trees. Following are scenes of Erikson and myself walking along one of the trails looking up at the air plants on one of the giant *Bombacopsis* trees. Other subjects are the tamandua, tree formicaria, three-toed sloth, marmosets, howlers, toucans and other birds, the sensitive mimosa, the zebra swallowtail, the *Heliconia*, the beau-

tiful blue princess Morpho, and of course, the coatis. My still photographs include many of the above subjects.

"As I mentioned on my arrival in the Zone, my trip was one of examination to discover material for a full-length educational film. In Chiriquí Province at the foot of El Volcán de Chiriquí, I found what I was looking for in the quetzal bird—they breed in March in that region and are said to be easily accessible at that time. So far, I believe only two persons have photographed them in color—Wolfgang von Hagen and Luis Marden of the National Geographic. I hope to make a complete film in color on the nesting habits of this beautiful bird.

"Returning to the film which I made last summer, I have presented it to several clubs and groups along with my own narration, and it has been very well received. It has aroused a great deal of interest in Panamá in general and in Barro Colorado in particular."

E. L. MIDDLESWART, technologist of the Forest Products Laboratory at Madison, Wis., and at present with the State Commission of Forestry of South Carolina, showed an intense interest in the life of the island. His report follows, and it must be understood that it is still too early for final conclusions. The fact remains that the island certainly has all that is needed for tests of this sort.

"We were endeavoring to find a plywood which would withstand tropical jungle conditions. We had some 1,500 samples of plywood 14 inches square made of 4 different species of wood (red gum, douglas fir, cottonwood, and birch) glued with 12 different glues and glue mixtures, and given 5 different surface treatments on exposure on the island. One-half of the samples were placed on racks in the sunlight and the other half were placed on racks in the deep jungle to give a comparison between the two conditions. The samples were made at the laboratory in Madison, Wis., and flown to the Zone by the Army Air Forces. They were placed on exposure in January 1946.

"The laboratory also sent the plywood wing-section panels for exposure on B. C. I., which came shortly after I left the Canal Zone. These wing sections were also sample sections of plywood used in studying the effects of tropical weather conditions upon various glues and woods used in making the plywoods and to find which glues and woods are the most satisfactory for use in the Tropics.

"This covers the high points of our work there. I might add that the conditions were most nearly ideal on B. C. I. for this study. It will be some time before the results are compiled."

WILLIAM E. LUNDY, of the paymaster's office of the Panama Canal, and also secretary-treasurer of the Panama Canal Natural History Society, spent 3 days during the rainy season on the island, and being deeply interested in natural history, and a keen observer, his brief

report is of much interest. It shows what others, who are much more versed in zoology, can expect to find. And since these animals on the island are as nature has them, not in cages, but in the open, to see and observe them is to know them as they really are. To the ecologist, to the student of animal behavior, to the general naturalist, it is to see, smell, hear, feel, and touch that which is life. It is something that books can only feebly portray. We have the orderly sequence of external nature, we have the living organism moving about in this environment inhabited by other species, and we have that continuous adjustment which constitutes life.

This is what Lundy saw in but 3 days: 10 bands of howler monkeys, 3 of the white capuchins, 2 of marmosets. He saw any number of the coatimundi, peccary, squirrels, 2 deer, many nequi, 1 tayra, and best of all, 1 night monkey (Goldman's *Aotus zonalis*). He came across 10 "armies" of army ants, and one huge bivouac of these most interesting ants. Among the birds he saw large numbers of toucans, parrots, and guans, also the tinamou, pileated woodpeckers, ant-shrikes, motmots, two king vultures, many of the other vultures, the scarlet-capped manikin, Ghiesbrecht's hawk, and others. Among the insects, perhaps the most spectacular were the large metallic blue *Morpho* butterflies, another butterfly with transparent front wings and pink hind wings, and the graceful large "helicopter" dragonfly.

COMMENTS OF SCIENTISTS

"Life at the Island was a pleasant experience and I am telling my associates about conditions there. It seems to me to be an ideal place for the conduct of experimental studies of many types, and I would like to thank you for the opportunity to work there. The research station is certainly a well-run place."—Dr. JAMES B. HAMILTON.

"My report is incomplete, of course, since it includes no statement of how thrilling and how great a privilege it was to return to the island to continue my work where I left it off, to meet and talk with you again, and to enjoy once more directly the countless emotional and perceptual satisfactions that come from hiking and strolling around, and from just standing in the many well-remembered landmarks, probably I had best leave the sentimental part of the return unsaid; at least the above sentence is sufficiently full of rushing verbal chaos to represent how I felt on February 7, 1946, and all of the days I was there."—Dr. T. C. SCHNEIRLA.

"The severity of conditions conducive to deterioration and the excellent facilities for scientific study, make the island an ideal location for such investigations."—JOSEPH KOWAL.

"As for the Naval Medical Research Institute, the island would be a most useful proving ground for many of the things developed here.

These include insecticides and repellents, warm-weather clothing and footgear, a new type of salt tablet for men perspiring profusely, etc. In addition to all of the above, the island is a wonderful place for a boreal biologist to broaden his outlook."—GROVER C. PITTS.

"With reference to my visit to B. C. I., I certainly want to put in my plug. I surely enjoyed my visit there, not only with reference to my work, but with reference to the many, many other phases of study adapted to the area. I certainly had my eyes opened as to jungle conditions and the flora and fauna therein. I have never been in a place where so many phases of biology in general could be so interestingly studied and all from the same roof. The beauty of the flowers and colorful birds still stands out in my memories of B. C. I., not to forget the hours I sat and watched the busy little monkeys playing in the trees.

"The fellowship which I experienced with the fellow scientists working and visiting the island, as well as the friendly reception of the native people welcoming me to B. C. I., is an experience never to be forgotten."—EUGENE L. MIDDLESWART.

"To the visitors of the Barro Colorado Laboratory! May they get from the trails in the rain forest such an inspiration as will last them through life and make them ardent protectors of the tropical forests of the world, for without their aid these marvels of beauty will surely disappear forever."—DAVID FAIRCHILD.

"I take up my pen with the greatest of pleasure to record the outstanding impressions left by my recent visit to Barro Colorado Island. When I recall the expeditions I have made into Central American jungles, the great expense involved, and the meager equipment permitted by pack-mule transportation, the difficulties encountered and the usual sequellae of tropical malaria and dysentery, it is only natural that I should be struck first of all by the propinquity and safety of Barro Colorado Island.

"Just to think that one can drop off a chair car at a railway station in a civilized community, and after half an hour's launch ride find one's self in the heart of virgin tropical forest, is to feel a wave of admiration for the foresight of those who secured the reservation of this great tract to scientific purposes. It is a biologist's fantasy come true, and I hope as time goes on that more and more of our scientific institutions will come to its support, so that the potentialities of the laboratory can be developed in all directions, and utilized to the full at all times of the year.

"I believe there is nothing like it in the world. There are great botanical and zoological gardens in the Tropics which represent an attempt to facilitate man's acquaintance with tropical nature by transporting the flora and fauna to some easily accessible place. Barro

Colorado Island has the opposite aim, of enabling man to transport himself into the midst of tropical nature and to live there for any period of time in comfort and safety.

"Nature lovers as well as scientists can enjoy this unusual experience. My wife was as excited as I was on our morning walks, at the hundred and one novel things she had read about but never seen. We were equally lucky in sighting mammals and birds before they took alarm, while the trees and plants always stood still to be admired. I was struck by the intelligence and alertness of our Panamanian guide Silvestre, and his knowledge of jungle life.

"In short, I am enthusiastic about Barro Colorado and I will not fail to endeavor to communicate this feeling to my friends."—Dr. L. W. HACKETT, *Rockefeller Foundation*.

"As the result of my recent visit to Barro Colorado Island I feel impelled to write you to express my gratification with what is being accomplished. I remember my pleasure when the isolation of this area by the waters of Gatun Lake was first foreseen, and the decision was made to make it a permanent preserve for native life. Yet I can see now that I had a very inadequate idea of the realities of nature in that area; and an equally inadequate idea of what might be attempted in the way of scientific observation, experiment, and systematic record. I had, indeed, a general idea of the abundance of life in the jungle, but the scope of your records was a revelation. This means, partly, that the number of species is vastly greater than would be guessed, even by most scientific men. It also means (you must allow me to say this) that the work is being directed with wisdom and pushed with energy. That such records as I saw should be even attempted would seem to indicate the presence of a considerable staff, yet I could not help seeing that it is largely your own work. It is greatly to be hoped that your work will not only be continued, but augmented by further cooperation."—NEVIN M. FENNEMAN.

"I find it difficult to say anything about my general impression of Barro Colorado that does not sound exaggerated, trite, or exactly like something I have read somewhere else. Perhaps you will know how I feel when I say that I wish (financial considerations aside) that a stay on Barro Colorado could be required of every candidate for the doctor's degree in either botany or zoology. You may be amused to know that about a week after we returned to Chicago we went to Warren Woods, a beach-maple forest about 70 miles east of Chicago. It was very hot, 96° F., and the mosquitoes were indescribably thick. It was impossible to accomplish much, and we left after about 20 minutes. We both agreed then that we would a thousand times rather have the ticks and red bugs of B. C. I. than the mosquitoes of our temperate forests. In fact, when I begin to recount the virtues of that

little island it seems almost too good to be true. Of course we realize that the virtues of Barro Colorado Island are not entirely the result of its natural equipment. The well-marked trails, the laboratory, the library, the excellent living accommodations, the trail-end houses, and all the rest are the end results of a lot of patient planning and unending attention to detail. The summer of 1939 was the most stimulating and happiest one of our lives."—RALPH and MILDRED BUCHSBAUM.

"The island is better than ever; and after knocking about in parts of the world where it is very difficult to organize one's work, I appreciate more keenly than ever the possibilities Barro Colorado offers for profitable natural history studies which can be begun immediately upon arrival."—ALEXANDER F. SKUTCH.

"All light talk aside, I have not seen any place in my travels which compares with Barro Colorado Island in point of excitement of the field-naturalist kind. In Java and Sumatra the Dutch have built palatial laboratories, but these are far removed from the new, fresh, wild jungle. In Ceylon the British have an agglomeration of buildings like the United States Department of Agriculture, but it is surrounded on all sides by tea plantations. Everywhere it is the destructive activity of man that is clearing off the jungle and replacing the gorgeous forest with weedy growth or plantations of rubber trees in rows. Hold the virgin character of Barro Colorado at all costs.

"Tell the visitors to take it from one who has just been there that the conditions for studying tropical plants and animals are better at Barro Colorado Island than anywhere I went in Sumatra or Java."—DAVID FAIRCHILD.

"Barro Colorado Island is one of the most astounding places I have visited in any part of the world. Its value is tremendous for scientific research, even for research that has economic importance. I sincerely hope the day never comes when any of the land is devoted to investigations such as are now being carried on in many agricultural forest and range experiment stations. The virgin character of Barro Colorado is sufficient asset and I hope you will fight every move that may be made to change this condition."—FRANK E. EGLER.

"I must confess I was amazed at the systematic way in which the trails are laid out and posted, the filing system in the library and the many other modes and ways of doing things. I doubly appreciate this because I have been places where such systems were not followed, much to everyone's disadvantage."—GEORGE W. PRESCOTT.

"Never again shall I make a trip like this one for merely 5 weeks. If I cannot make a trip next summer I am certainly going to make every effort to get down the following one. Caylor too, wants to get back to Barro Colorado Island and go through with our contemplated project of preparing a flora of the ferns of the region. We have a siz-

able collection of ferns now on hand. In my algae collection I find 250 samples, many of which are simply loaded with species and I have no idea how many will appear in the final list. I think 500 would be a very modest estimate and very likely there will be many more than that when the diatoms are included."—GEORGE W. PRESCOTT.

"Even without special precautions, the island would seem to be safer, hygienically speaking, than most areas of like size in the United States.

"Certainly all of the minimum requirements for successful laboratory work are fulfilled on the island. In addition to these minimum facilities the laboratory possesses a remarkable versatility of equipment as well as adequate laboratory space. And while it is obvious that special equipment to suit the needs of the individual scientist must be supplied by him, it is comforting to know that many laboratory necessities are accessible in a small clearing in a tropical rain forest."—PAUL D. VOTH.

"The island is more than ever a paradise for the biologist. Living conditions are excellent, the food is fine, the resident staff efficient and courteous. The forest offers a pageant of life which is the ideal laboratory for the study of the principles of biology. Not only has it proved to be of great value for the undergraduates, but its worth for the teacher has hardly been realized by more than a few. *Every university and college* ought to send the members of its staff in the biological sciences for a sojourn on the island, *not once but periodically. It would be an economical investment in the improvement of teaching.* This is especially true now when all emphasis is on the experimental side with the result that so many workers know very little about the organisms with which they work. The island will be an excellent place for studies in plant and animal physiology. The rapid growth rate of plants would aid such work tremendously."—ROBERT N. WOODWORTH.

"In addition to the value of publications based on work on Barro Colorado, who can estimate the influence of observations, studies, and photographs which have formed the basis of unnumbered addresses in lecture hall and classroom, or the educational value of museum exhibits depicting island life? In brief, during their 15 years as a laboratory, the 4,000 acres we know as Barro Colorado have contributed more to our knowledge of tropical wildlife than any other area of similar extent in America—perhaps in the world."—FRANK M. CHAPMAN.

THE SPECIES INDEX

A 5- by 8-inch card index is kept for each species of plant and animal definitely known from the island. Each card lists the scientific name, the major division to which it belongs, and the family name; also the

name of the collector, the name of the person who made the determination, when and where collected, and other pertinent details.

These cards are indexed first according to the major phyla—mammals, birds, reptiles, amphibians, fish, arthropods, etc.—which are further subdivided into superorders, orders, etc., and finally by families. Under each family the genera are in alphabetical order, and the species for each genus are also in alphabetical order.

This index is invaluable to the student. It is a unique record of the life of the island. In 1940 the index covered a total of 4,924 species of plants and animals, representing 2,805 genera. In plants alone there were 747 genera and 1,437 species. Since 1940 new entries have been made, but no count has been made of the present number, owing to pressure of other duties, especially those concerned with the war effort. A conservative estimate is about 7,000 species.

Extensive collections have been made of algae, fungi, and lichens, but because of the war, reports on these have not yet been published. Lesser collections were made in other groups. A conservative estimate would be fully 700 species.

THE ISLAND HERBARIUM

The herbarium consists of 1,533 mounted specimens, representing 806 species, not including the mosses. These sheets are in genus covers, and the collection is arranged in four major groups, the cryptogams, ferns, monocotyledons, and dicotyledons. In each of these groups the genus covers are grouped according to the families, and these, for convenience in handling, are alphabetically arranged. There are on hand more than 2,500 additional named specimens as yet unmounted and these will probably swell the number of species to close to 1,200.

The herbarium is a most valuable adjunct to a laboratory such as ours. It does more than supplement the botanical library. Too often botanical literature is of little help to one not a trained botanist, and for this majority of students, the herbarium is what is needed.

NEEDS

The most urgent needs are for a concrete water tank to replace wooden tanks now in bad condition; new septic tanks; painting of all buildings, inside and out; herbarium and other storage cases; replacement of bedding and purchase of additional furniture; and miscellaneous repairs to buildings: It is estimated that these present most urgent needs could be met at a cost of \$10,000.

Other needs that should be met promptly are for a more adequate supply of electricity; a new fireproof building to house the library, photographic equipment, herbarium, and records; and adequate

animal cages to keep various creatures in captivity during scientific investigations.

TERMITE-FREE BUILDINGS IN THE TROPICS

Is it possible to build comfortable, well-ventilated houses of lumber and not have a termite hazard? The answer is "Yes." However, few architects go to the trouble of getting the necessary information.

We have 57 known species of termites in Panamá and the Canal Zone. Of these, 45 species occur on Barro Colorado Island. Two of the most destructive in the world occur here, one of which is known to eat through the lead sheathing of electrical cables. The rapidity of destruction by some of the species is incredible. Some even work in living trees, and we have records of fruit orchards destroyed by them.

And yet on Barro Colorado Island we have buildings where we let the termites do whatever they wanted to do—eat up the building overnight if they could—and yet these buildings are in excellent

In 1926 we built a test house at the end of Drayton Trail, 16 feet square and 10 feet high, set on wooden posts extending 3 feet into the ground. The timber used was pressure treated with coal-tar creosote and with zinc chloride. The wallboard is treated with chromated zinc chloride. In the May 1947 number of *Wood Preserving News* Dr. Thomas E. Snyder, senior entomologist of the Bureau of Entomology and Plant Quarantine, published all details and results of his inspection in February of this year, showing no damage anywhere due to termites, and yet termites tried to get a hold. The building is in excellent condition after 21 years. It is true that pressure treatment increases the original cost of the timbers, but it is cheap insurance. A building of untreated timbers would have been destroyed in less than a year.

At the end of the Pearson Trail we have the Fuertes House, built in February 1931, 16 years ago. It is set on nine posts; hence there is good ventilation under the house. With the exception of the shingles, which are of red cedar (and need replacement), all the wood and timbers, including posts, were treated with zinc-meta-arsenite. The tables and chairs are also so treated. There is no damage anywhere to the treated wood. The wallboard also was zinc-meta-arsenite treated. It likewise is free of any termite damage. Test stakes of untreated wood half-buried in the ground near the building were destroyed within 8 months.

Furthermore, this zinc-meta-arsenite treated building is free of cockroaches. No steps are taken to keep termites out of the building, and no termite shields are used—hence, termites have absolute free-

dom to work if they can. Yet the building is in as excellent shape as when we first put it up. Here again, treated lumber costs perhaps 50 percent more, but as it gives freedom from termites, in a few years it pays for itself.

The above two cases show that with treated timbers you can build a termite-free house even where termites are extremely abundant and active.

Tests on the island also show that one can build of untreated timbers and have no termite hazard, provided a few simple precautions are taken. The main requirement is to build a good thick concrete floor which will extend out at least to the line of the eaves. The floor must be well made, with no cracks. The secret is to make an inspection at least once a week around this concrete floor, and if termites have built any covered runways, introduce into these runways either powdered calomel or finely powdered paris green. In this way the colony is poisoned, and by watching a treated runway, it can easily be determined whether or not the job was well done. It takes so little time and does not need superior knowledge. Of course there must be no leaks, either in the roof or in the plumbing.

Of course, by the use of properly made termite shields, properly installed, it is possible to keep termites out of buildings. Where it is possible to install them, termite shields are cheap protection, but not all buildings lend themselves to the use of shields. Soil poisons also are the answer for some type of buildings, but vigilance is always necessary, and inspection cannot be perfunctory.

Circular 683, United States Department of Agriculture, "Effectiveness of Wood Preservatives in Preventing Attack by Termites," by Snyder and Zetek, gives a good picture of the extensive termite tests on Barro Colorado Island since 1923. The annual progress reports by Hunt and Snyder in the Annual Reports of the American Wood Preservers' Association give details of the more important of these tests. Nearly 4,000 tests are involved, in addition to the Kowal-Dews-Johnston series noted elsewhere in this report.

LIST OF THE TERMITES OF PANAMÁ AND THE CANAL ZONE

In this, the latest list, 57 species are represented, and of these, 45 are known from Barro Colorado Island (indicated by the initials BCI). There are 13 new species which will be described in the near future by Dr. Emerson. The *Kalotermitidae* are those commonly known as the "dry-wood termites." The *Rhinotermitidae* are the bad actors, *Coptotermes niger* and *Heterotermes tenuis* being especially noted for their destructiveness. Some of the *Termitidae* are also very destructive. This list is by no means final. We feel that at least 15 more species will be discovered.

KALOTERMITIDAE (15)

1. *Kaloterмес* (*K.*) *clevelandi* Snyder.
2. *Kaloterмес* (*K.*) *marginipennis* (Latreille).
3. *Kaloterмес* (*K.*) *tabogae* Snyder.
4. *Kaloterмес* (*Neoterмес*) *holmgreni* Banks (BCI).
5. *Kaloterмес* (*Neoterмес*), n. sp.
6. *Kaloterмес* (*Neoterмес*), n. sp.
7. *Kaloterмес* (*Rugiterмес*) *isthmi* Snyder (BCI).
8. *Kaloterмес* (*Rugiterмес*) *panamae* (Snyder) (BCI).
9. *Kaloterмес* (*Cryptoterмес*) *breviarticulatus* Snyder.
10. *Kaloterмес* (*Cryptoterмес*) *dudleyi* Banks.
11. *Kaloterмес* (*Lobiterмес*) *longicollis* (Banks).
12. *Kaloterмес* (*Calcariterмес*) *brevicollis* (Banks) (BCI).
13. *Kaloterмес* (*Calcariterмес*) *emarginicollis* (Snyder) (BCI).
14. *Kaloterмес* (*Glyptoterмес*) *augustus* Snyder.
15. *Kaloterмес* (*Glyptoterмес*), n. sp. (BCI).

RHINOTERMITIDAE (5)

16. *Coptoterмес* *niger* Snyder (BCI).
17. *Heteroterмес* *tenuis* (Hagen) (BCI).
18. *Heteroterмес* *convexinotatus* (Snyder) (BCI).
19. *Prorhinoterмес* *molinoi* Snyder (BCI).
20. *Rhinoterмес* (*R.*) *longidens* Snyder (BCI).

TERMITIDAE (37)

21. *Corniterмес* (*C.*) *agnathus silvestri*, var. *Walkeri* Snyder (BCI).
22. *Armiterмес* (*A.*) *armigera* (Motsch.) (BCI).
23. *Armiterмес* (*A.*) *chagresi* Snyder (BCI).
24. *Armiterмес* (*Rhynchoterмес*) *peramatus* Snyder (BCI).
25. *Nasutiterмес* (*N.*) *columbicus* (Holmgren) (BCI).
26. *Nasutiterмес* (*N.*) *cornigera* (Motsch.) (BCI).
27. *Nasutiterмес* (*N.*) *ephratae* (Holmgren) (BCI).
28. *Nasutiterмес* (*N.*) *pilifrons* (Holmgren) (BCI).
29. *Nasutiterмес* (*Subuliterмес*) *kirbyi* Snyder (BCI).
30. *Nasutiterмес* (*Subuliterмес*) *zeteki* Snyder (BCI).
31. *Nasutiterмес* (*Subuliterмес*), n. sp. (BCI).
32. *Nasutiterмес* (*Obtusiterмес*) *panamae* Snyder (BCI).
33. *Nasutiterмес* (*Convexiterмес*) *clevelandi* Snyder (BCI).
34. *Nasutiterмес* (*Uniformiterмес*) *barrocoloradoensis* Snyder (BCI).
35. *Cylindrotermes* *macrognathus* Snyder (BCI).
36. *Amiterмес* (*A.*) *beaumonti* Banks (BCI).
37. *Amiterмес* (*A.*) *medius* Banks *foreli* Wasmann (BCI).
38. *Anoploterмес* (*A.*) *gracilis* Snyder (BCI).
39. *Anoploterмес* (*A.*) *parvus* Snyder (BCI).
40. *Anoploterмес* (*A.*), n. sp. (BCI).
41. *Anoploterмес* (*A.*), n. sp. (BCI).
42. *Anoploterмес* (*A.*), n. sp. (BCI).
43. *Anoploterмес* (*A.*), n. sp. (BCI).
44. *Anoploterмес* (*A.*), n. sp. (BCI).
45. *Anoploterмес* (*A.*), n. sp. (BCI).
46. *Anoploterмес* (*A.*), n. sp. (BCI).
47. *Anoploterмес* (*A.*), n. sp. (BCI).

48. *Anoplotermes* (A.), n. sp.
49. *Anoplotermes* (A.), n. sp.
50. *Anoplotermes* (*speculitermes*), n. sp.
51. *Microcerotermes arboreus* Emerson (BCI).
52. *Microcerotermes exiguus* (Hagen) (BCI).
53. *Termes* (T.) *hispaniolae* (Banks) (BCI).
54. *Termes* (T.) *panamensis* (Snyder) (BCI).
55. *Termes* (T.), n. sp. (BCI).
56. *Orthognathotermes wheeleri* Snyder (BCI).
57. *Capritermes* (*Neocapritermes*) *centralis* Snyder (BCI).

RAINFALL, TEMPERATURES, AND RELATIVE HUMIDITY, 1946

In the 22 years of record, 1946 was the third driest year. The rainfall amounted to only 87.38 inches, showing a deficiency of 21.43 inches. This deficiency was most pronounced in the wet season, amounting to 17.93 inches. Only 2 months, July and September, had an excess, which, however, was very slight—0.77 and 0.20, respectively. There was a total deficiency of 3.50 inches in the dry season, January to April, inclusive; only March showed a small excess—0.25 inch. February was the driest month (0.32 inch) and November the wettest (14.98 inches). Table 1 gives the total yearly rainfall, and the station average, for each year from 1925 to 1946, inclusive.

TABLE 1.—Annual rainfall, Barro Colorado Island, Canal Zone

Year:	Total inches	Station average	Year:	Total inches	Station average
1925-----	104. 37	-----	1936-----	93. 88	108. 98
1926-----	118. 22	113. 56	1937-----	124. 13	110. 12
1927-----	116. 36	114. 68	1938-----	117. 09	110. 62
1928-----	101. 52	111. 35	1939-----	115. 47	110. 94
1929-----	87. 84	106. 56	1940-----	86. 51	109. 43
1930-----	76. 57	101. 51	1941-----	91. 82	108. 41
1931-----	123. 30	104. 69	1942-----	111. 10	108. 55
1932-----	113. 52	105. 76	1943-----	120. 29	109. 20
1933-----	101. 73	105. 32	1944-----	111. 96	109. 30
1934-----	122. 42	107. 04	1945-----	120. 42	109. 84
1935-----	143. 42	110. 35	1946-----	87. 38	108. 81

Table 2 gives the rainfall by months for the years 1945 and 1946, the station average for each month, the excess or deficiency for each month and the accumulated plus or minus, and also the maximum rains each month for 5 and 10 minutes, and 1 and 24 hours. These maximum values are consecutive wherever that maximum occurred; hence the 24-hour record is not necessarily from midnight to midnight.

Table 3 gives the number of hours of rain each month for 1946 and the total amount in inches, and then these data separated into the four 6-hour periods. These data are of interest in that they indicate when most rains may be expected. From 6 a. m. to noon there is less rainfall than from noon to 6 p. m.

TABLE 2.—*Comparison of 1945 and 1946 rainfall; and maximum rains for short periods*

Month	Total		Station average	Years of record	Plus or minus	Accumulated E. or D.	Maximum rains			
	1945	1946					5 minutes	10 minutes	1 hour	24 hours
January.....	2.89	.45	1.91	21	-1.46	-1.46	.10	.14	-----	.16
February.....	.67	.32	1.23	21	-.91	-2.37	.09	.10	-----	.20
March.....	.27	1.71	1.46	21	+ .25	-2.12	.15	.19	-----	.69
April.....	1.59	1.41	2.79	22	-1.38	-3.50	.21	.25	-----	.37
May.....	13.55	8.05	11.13	22	-3.08	-6.58	.25	.40	-----	.65
June.....	10.17	7.94	11.27	22	-3.33	-9.91	.35	.50	-----	1.13
July.....	13.87	12.58	11.81	22	+ .77	-9.14	.33	.60	-----	1.69
August.....	12.32	10.50	12.56	22	-2.06	-11.20	.34	.60	-----	2.41
September.....	10.07	10.67	10.47	22	+ .20	-11.00	.33	.62	-----	4.91
October.....	10.02	9.00	13.17	22	-4.17	-15.17	.40	.60	-----	2.50
November.....	20.60	14.98	19.30	22	-4.32	-19.49	.60	1.05	-----	1.20
December.....	24.40	9.77	11.71	22	-1.94	-21.43	.46	.82	-----	4.51
Year.....	120.42	87.38	108.81	-----	-----	-21.43	-----	-----	-----	3.42
Dry.....	5.42	3.89	7.39	-----	-----	-3.50	-----	-----	-----	-----
Wet.....	115.00	83.49	101.42	-----	-----	-17.93	-----	-----	-----	-----

TABLE 3.—*Rainfall 1946. Total number of hours of rain and amount in inches for the daily 6-hour period*

Month	Midnight to 6 a. m.		6 a. m. to noon		Noon to 6 p. m.		6 p. m. to midnight		Midnight to midnight	
	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount
January.....	9	.12	3	.20	5	.05	3	.08	20	.45
February.....	8	.18	3	.13	1	.01	-----	-----	12	.32
March.....	10	.19	18	.55	12	.94	3	.03	43	1.71
April.....	9	.32	4	.25	6	.73	8	.11	27	1.41
May.....	11	2.97	12	.69	20	4.81	5	.08	48	8.05
June.....	19	1.84	10	2.41	32	4.08	11	.61	72	7.94
July.....	26	1.63	15	2.19	48	6.13	19	2.63	106	12.58
August.....	19	.54	20	2.70	39	6.84	16	.42	84	10.50
September.....	25	1.64	16	1.46	38	5.88	9	1.69	88	10.67
October.....	25	1.22	22	1.08	38	4.03	19	1.77	104	9.00
November.....	34	5.29	24	2.44	29	5.41	27	1.84	114	14.98
December.....	37	2.44	21	1.92	31	3.78	23	1.63	112	9.77
Year.....	232	17.38	163	16.92	289	42.19	143	10.89	832	87.38
Dry.....	36	.81	28	1.13	24	1.73	14	.22	102	3.89
Wet.....	196	16.57	140	15.79	265	40.46	129	10.67	730	83.49

Table 4 gives a summary and analysis of the 1946 rainfall for the entire year and for the dry and wet seasons, both as to hours and days, percentage of the total possible hours (if it rained every hour), and these data are significant. With so much less rainfall in the dry season, and particularly with so high a deficiency, the animals have a hard time getting food. The peccary in the dry season is noticeably thin—very different from his condition in the wet season when food is more plentiful. The effects of moisture are profound. This struggle for food is also reflected in the rate of reproduction in certain of the mammals. A bad year, deficient in rainfall and in food, increases the rate of reproduction, and conversely, a year of abundant rainfall, an abundance of food, shows in some mammals a falling off in this rate.

TABLE 4.—*Summary and analysis of the 1946 rainfall for the year, and for the dry and wet seasons*

ENTIRE YEAR	
Total hours of rain.....	832
Percentage of total possible hours.....	9.50
Total days of rain.....	233
Percentage of total possible days.....	63.84
DRY SEASON	
Total hours of rain.....	102
Percentage of total possible hours.....	3.54
Total days of rain.....	44
Percentage of total possible days.....	36.67
Amount of rain in inches.....	3.89
Percentage of total rainfall for year.....	4.45
WET SEASON	
Total hours of rain.....	730
Percentage of total possible hours.....	12.42
Total days of rain.....	189
Percentage of total possible days.....	77.14
Amount of rain in inches.....	83.49
Percentage of total rainfall for year.....	95.55

In table 5 are given (1) the number of hours and the amount of rains of 0.40 inch or more per hour, for each of the four 6-hour periods, and (2) the three heaviest rains each month (midnight to midnight). Rains of 0.40 inch per hour, if rather evenly distributed, will not seriously hamper field work, but if such rains come down in 5 minutes, it is another story.

TABLE 5.—*The three heaviest rains each month and number of hours and amount of rains of 0.40 inch or more per hour for 1946*

Month	Total inches	Days of rain	Hours of rain	Midnight to 6 a. m.		6 a. m. to noon		Noon to 6 p. m.		6 p. m. to midnight		3 heaviest rains (midnight to midnight)
				Number	Amount	Number	Amount	Number	Amount	Number	Amount	
January.....	.45	11	20									.14 .08 .05
February.....	.32	7	12									.16 .06 .04
March.....	1.71	14	43									.68 .58 .10
April.....	1.41	12	27									.73 .29 .17
May.....	8.05	16	48	2	1.59	0		4	2.85			2.99 1.14 .85
June.....	7.94	21	72			3	1.63	3	2.37			1.71 1.69 .95
July.....	12.58	24	108			3	1.50	3	2.48	2	1.68	2.48 1.91 1.33
August.....	10.50	27	84			1	1.65	4	4.45			4.40 1.77 .91
September.....	10.67	26	88	1	.46	1	.50	4	3.51	2	1.52	2.14 1.67 .96
October.....	9.00	25	104			1	.90	2	1.28	1	.51	1.15 .91 .82
November.....	14.98	29	114	4	3.80	1	.40	3	3.45	1	.41	2.54 2.49 2.12
December.....	9.77	21	112	1	.47	1	1.10	2	1.50	1	.67	3.35 1.18 1.05
Year.....	87.38	233	832	8	6.32	11	7.68	25	21.89	7	4.79	22.47 13.77 9.35
Dry.....	3.89	44	102	0	0	0	0	0	0	0	0	1.71 1.01 .36
Wet.....	83.49	189	730	8	6.32	11	7.68	25	21.89	7	4.79	20.76 12.76 9.01

During the dry season, there were no rains of 0.40 inch per hour during 1947, and only 51 such hours in the wet season, amounting to 40.68 inches, or 46.6 of the total rainfall for the year. And these 40.68 inches fell during only 6.1 percent of the total hours we had rain. This means that the balance, 46.70 inches, fell during 781 hours, or an average of only .06 inch per hour. The three heaviest rains each month amounted to a total of 45.59 inches in only 36 days. This leaves only 41.79 inches for the remaining 197 days.

Considering now these three heaviest rains each month (midnight to midnight), we have the following interesting data :

Dry season : 12 days, 3.08 inches, or 79.2 percent of the dry season total.

Wet season : 24 days, 42.53 inches, or 50.9 percent of the wet season total.

The year : 36 days, 45.61 inches, or 52 percent of the year's total.

The remaining days when it rained show :

Dry season : 32 days, 0.32 inch, or an average of 0.01 inch per day of rain.

Wet season : 165 days, 40.96 inches, or an average of 0.248 inch per day of rain.

The year : 197 days, 41.79 inches, or an average of 0.212 inch per day of rain.

For comparison, the following tables are presented, covering the rainfall for other localities in the Canal Zone and Republic of Panamá data on temperatures, relative humidities, barometric pressures, etc. ; and the maximum and minimum yearly rains of record for 19 important localities. These data are taken from the reports of the Chief Meteorologist of the Panama Canal. They give a better understanding of the climate, and it is only to be regretted that comparable data are not available for a great many more localities in the Republic of Panamá. To an ecologist, these data are of inestimable value.

TABLE 6.—*Annual rainfall at other Panamá stations, in inches*

	Total, 1946	Station average	Excess or deficiency	Years of record
Balboa.....	50.06	68.84	-18.78	48
Pedro Miguel.....	63.18	80.14	-16.96	39
Summit.....	76.00	86.94	-10.94	23
Gamboa.....	65.37	88.86	-23.49	64
Madden Dam.....	79.62	97.86	-18.24	47
Frijoles.....	94.39	106.64	-12.25	35
Bohío.....	99.67	95.14	+4.53	29
Trinidad.....	88.61	110.03	-21.42	23
Monte Lirio.....	95.43	118.71	-23.28	39
Gatun.....	121.83	125.30	-3.47	42
Cristobal.....	126.62	130.37	-3.85	76
Porto Bello.....	170.63	160.78	+9.75	35
Porto Armuelles.....	62.21	92.46	-30.25	17
Sta. Rosa.....	54.06	68.17	-14.11	21
Salamanca.....	90.30	100.74	-10.44	35
Chilibrillo.....	80.12	97.81	-17.69	35
Candelaria.....	120.95	131.64	-10.69	13
Peluca.....	103.12	123.10	-19.98	13

TABLE 7.—*Maximum and minimum rainfall, Barro Colorado Island, 1925 to 1946*

	Maximum	Minimum		Maximum	Minimum
January.....	4.60	.45	August.....	21.44	5.93
February.....	5.91	.05	September.....	19.96	6.07
March.....	5.54	.19	October.....	22.23	6.06
April.....	7.61	.10	November.....	41.59	7.21
May.....	19.02	3.09	December.....	28.15	1.88
June.....	19.31	5.43			
July.....	28.58	5.52	Year.....	143.42	76.57

TABLE 8.—*1946 pressure, temperature, relative humidity, etc.*

	Balboa Heights	Madden Dam	Cristobal
Pressure (reduced to sea level):			
Maximum.....	30.010	29.990	30.010
Minimum.....	29.680	29.660	29.680
Annual mean (b)hourly.....	29.831	29.817	29.843
Temperature (Fahrenheit):			
Annual mean.....	79.6	77.9	79.9
Absolute maximum.....	97	96	90
Mean daily maximum.....	88.2	87.3	83.8
Absolute minimum.....	69	64	70
Mean daily minimum.....	74.0	72.0	76.5
Greatest daily range.....	23	26	16
Mean relative humidity (percent).....	82.8	82.8	82.2
Mean wet thermometer ¹	74.1	73.9	75.4
Mean dew point ¹	73.1	72.9	73.8
Mean vapor pressure ¹	.814	.807	.835

¹ Mean of 8 a. m. observations except Cristobal which is the mean of 8 a. m., and 8 p. m. values. Mean relative humidity is bihourly mean.

TABLE 9a.—*Maximum amounts of precipitation in inches (years of record)*

	5 minutes	10 minutes	1 hour	24 hours	Year
Balboa.....	.90	1.68	4.78	7.57	93.06
Balboa Heights.....	.69	1.27	4.49	7.23	91.42
Pedro Miguel.....	.73	1.23	3.85	8.53	110.57
Madden Dam.....	.68	1.20	4.19	9.31	152.04
Gamboa.....	.65	1.17	3.85	7.48	136.19
Barro Colorado.....	.85	1.40	3.57	10.48	143.42
Gatun.....	.68	1.36	5.68	12.25	164.19
Cristobal.....	.66	1.20	5.16	13.60	183.41

TABLE 9b.—*Maximum amounts of precipitation in inches (1946)*

	5 minutes	10 minutes	1 hour	24 hours
Balboa.....	.45	.80	2.54	3.19
Balboa Heights.....	.49	.88	3.26	3.92
Pedro Miguel.....	.45	.85	2.00	3.92
Madden Dam.....	.65	1.15	3.55	4.87
Gamboa.....	.52	.95	2.14	3.99
Barro Colorado.....	.60	1.05	2.29	4.91
Gatun.....	.59	1.00	2.11	4.74
Cristobal.....	.45	.80	3.30	8.41

TABLE 10.—*Temperatures (Fahr.) and relative humidity, Balboa Heights (B. H.) and Cristobal (Xbal), 1946*

Monthly mean			Maximum				Minimum				Relative humidity	
			B. H.		Xbal		B. H.		Xbal			
1946	B. H.	Xbal	Abs.	Mean	Abs.	Mean	Abs.	Mean	Abs.	Mean	B. H.	Xbal
January	78.7	80.4	90	88.0	88	84.4	69	72.4	73	76.9	78.1	75.6
February	79.2	79.7	92	89.4	87	83.5	69	72.6	75	76.8	73.0	75.1
March	80.3	79.8	93	90.6	88	83.7	70	73.4	74	77.2	71.9	75.8
April	81.7	81.1	97	92.2	87	85.1	70	74.7	77	78.2	72.8	76.8
May	80.9	80.8	96	89.0	90	84.7	72	75.5	71	77.6	83.3	83.3
June	80.5	80.6	94	75.4	87	77.4	72	75.4	70	77.4	85.8	86.0
July	80.3	79.8	92	88.3	86	83.5	72	75.5	72	76.7	86.0	87.2
August	79.4	79.8	92	86.9	86	82.7	69	74.7	70	76.6	87.6	87.1
September	78.9	79.1	91	86.4	88	83.4	71	74.2	72	75.5	89.5	87.4
October	78.2	79.0	89	86.0	90	84.0	71	73.2	72	74.9	88.3	84.1
November	78.0	78.9	90	85.9	90	83.2	71	72.7	71	74.7	89.1	83.3
December	78.9	79.6	90	86.8	86	82.9	70	73.1	71	75.9	87.6	84.1
Year	79.6	79.9	97	88.2	90	83.8	69	74.0	70	76.5	82.8	82.2
Dry	80.0	80.3	97	90.1	88	84.2	69	73.3	73	77.3	74.0	75.5
Wet	79.4	79.7	96	85.6	90	82.7	70	74.3	70	76.2	87.2	85.3

TABLE 11.—*Maximum and minimum annual rainfall of record, in inches (1946)*

	Maxi- mum	Mini- mum		Maxi- mum	Mini- mum
Balboa ¹	93. 06	48. 94	Cristobal ⁴	183. 41	86. 54
Pedro Miguel ¹	110. 57	58. 31	Porto Bello ⁴	237. 28	118. 04
Summit ²	111. 25	67. 57	Puerto Armuelles		
Gamboa ²	136. 19	62. 02	(Chiriqui).....	132. 32	58. 93
Madden Dam ³	152. 04	71. 95	Santa Rosa (Cocle).....	77. 20	48. 58
Frijoles ²	138. 36	78. 06	Tonosi (Los Santos).....	141. 03	51. 25
Barro Colorado ²	143. 42	76. 57	Salamanca ³	160. 46	69. 06
Trinidad ²	144. 48	87. 61	Chilibrillo ²	134. 23	72. 63
Monte Lirio ²	179. 73	85. 15	Candelaria ³	184. 98	101. 79
Gatun ²	164. 19	80. 31	Peluca ³	179. 64	91. 14

¹ Pacific drainage.² Gatun Lake drainage (Gatun Lake area).³ Gatun Lake drainage basin (Madden Lake watershed).⁴ Atlantic drainage.

FISCAL REPORT

During the fiscal year 1947, \$16,095.88 was available, none of which was appropriated by Congress. Of this amount, \$13,140.29 was spent, leaving on hand \$2,955.59 to begin the new fiscal year. In addition to this, \$3,183.96 is still on deposit, representing local collections, a total of \$6,139.55, to which will be added the few table subscriptions, an amount inadequate to take care of running expenses.

During the year \$4,403.96 was collected as fees from scientists for board and lodging, fees from visitors, and similar items. It is hard to say how much will be collected during the 1948 fiscal year, but it is almost certain that it will not be sufficient to carry us through the year.

The organizations listed below continued to aid materially in the support of the Laboratory through the payment of table fees:

American Museum of Natural History-----	\$300.00
Eastman Kodak Company-----	500.00
Harvard University-----	300.00
New York Zoological Society-----	300.00
Smithsonian Institution-----	300.00
University of Chicago-----	300.00

It is believed that more scientists will now be able to come to the island, and it is therefore imperative that more institutions and universities should help support the laboratory through table subscriptions. It is gratifying to report that Eastman Kodak Co. increased their subscription to \$1,000 a year.

Respectfully submitted.

JAMES ZATEK, *Resident Manager.*

Dr. ALEXANDER WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 11

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1947:

In this second postwar year of rehabilitation the work of the library was not greatly different in kind or amount from that of the previous year. Books are integral parts of the world of practical affairs as well as of ideas, and their production, distribution, and use, as well as their conception, follow the changing times. With the coming of peace there began a rise, not as yet very sharp, in the number of new books and serials important for the library to acquire. Prices rose and are still rising. The purchasing power of the inelastic allotment of book funds has correspondingly decreased. Paper shortages continued to limit the size of editions, and not a few new books went so quickly out of print as to make it difficult to get those for which prepublication orders had not been placed. Many fine and desirable works came into the old book market but prices were too high and funds too small to make it possible to buy more than a few of those most immediately important to the work of the Institution.

Among the more noteworthy of the 1,693 purchased books were the following: *Description Méthodique du Musée Céramique de la Manufacture Royale de Sèvres*, by Alexandre Brongniart and others, 1845; *Mammals of Amazonia*, by Eladio da Cruz Lima, volume 1, 1945; *A Monograph of Oriental Cicadidae*, by William Lucas Distant, 2 volumes, 1889-92; *Histoire de la Locomotion Terrestre, les Chemins de Fer*, by Charles Dollfuss and Edgar de Geoffroy, 2 volumes, 1935; *Illustrationes Florae in Insularum Maris Pacifici*, by Emmanuel Drake del Castillo, 6 portfolios, 1886-92; *The Royal Commentaries of Peru*, written originally in Spanish by Garcilaso de la Vega, el Inca, and rendered into English by Sir Paul Rycaut, 1688; *Histoire et Technique de la Montre Suisse de ses Origines à Nos Jours*, 1945; *The Etched Work of Whistler, Illustrated by Reproductions in Collotype of the Different States of the Plates*, compiled, arranged, and described by Edward G. Kennedy, 1 volume of text and 3 portfolios of plates, 1910; *The Artists of America, a Series of Biographical Sketches of American Artists, with Portraits and Designs on Steel*, by C. Edwards Lester, 1846; *The New World; the First Pictures of America*, made by John White and Jacques Le Moyne and engraved by Theodore

De Bry, with Contemporary Narratives * * * edited and annotated by Stefan Lorant, 1946; Thomas Nast, his Period and his Pictures, by Albert Bigelow Paine, 1904; Denmarks Fugle, by E. Lehn Schiøler, 3 volumes, 1925-31; De Vogels van Nederlandsch Indië, by H. Schlegel, 3 parts in portfolio, 1863-66; The Voyage of Gregory Shelekhof, a Russian Merchant, from Okhotzk, on the Eastern Ocean, to the Coast of America, in the Years 1783, 1784, 1785, 1786, 1787, and his Return to Russia, from his own Journal, 1795; Fregatten Eugenies Resa, 1851-1853, under Befäl af C. A. Virgin, by C. J. A. Skogman, 2 volumes in 1, 1854-55.

Gifts of the year came from 230 different donors and included some of the most useful additions to the library. Reprints and separates on special subjects from scientific and technical serials are indispensable working tools of the different divisions of the Institution, and the gifts of Dr. Ray S. Bassler and of A. B. Gahan of their personal collections of some 1,500 pamphlets each, on geology and on Hymenoptera, respectively, were most appreciated additions to the sectional libraries of geology and of insects. Paul Garber's gift of 147 books and pamphlets on aeronautics greatly strengthened the library's working collection of material in that field. As usual, the publications generously turned over by the American Association for the Advancement of Science and by the American Association of Museums supplied considerable material not received from other sources, and furnished numbers of useful duplicates as well. The library is deeply indebted to all its friends at home and abroad who have so kindly made contributions to its collections.

The total number of publications recorded by the accessions division for the year was 62,137. Of these, 14,607 came through the International Exchange Service, almost three times as many as in the year before. With the gradual return to more nearly normal conditions it is gratifying to find in how many cases the continuity of sets of foreign serials published abroad during the war will not be broken in the library because of the care with which they were reserved, stored, and later shipped by the institutions with which we were in regular exchange before the war. This encouraging aspect of the post-war situation, however, does not mean that there are not, unavoidably, a distressing number of series that ceased publication altogether during the war, some of them probably never to be resumed.

The filling of gaps in serial sets, foreign and domestic, current and old, requires eternal vigilance, and most of the 6,812 pieces received in response to our 589 requests were numbers of periodicals needed to fill such gaps, and were obtained chiefly in exchange. New exchanges arranged were 290.

Of the current accessions, 7,265 were cataloged or entered as additions to the Smithsonian Deposit in the Library of Congress, and most of these were additions to the great Deposit sets of publications of scientific institutions and learned societies, so important to research. Some of them were continuations of series that formed part of the original Smithsonian Deposit in 1866. In addition, all documents, dissertations, and other publications on subjects not found to be of immediate interest to the Institution were sent directly upon receipt to the Library of Congress, and they numbered 13,422.

Most but not all of the 10,749 publications transferred to the Department of Agriculture, the Army Medical Library, the Geological Survey, and other libraries of the Government, had been received during the year.

Our large collection of duplicates continued to be drawn upon in aid of destroyed libraries abroad, and 31,781 pieces were turned over to the American Book Center for this purpose.

The cataloging of currently received material was well kept up on the whole in spite of the handicaps of inadequate staffing of this vitally important part of the library's work. There is always the problem of the huge "backlog" of poorly or completely uncataloged older material, which is not only serious in itself but which inevitably slows up some of the work of cataloging new material which is related to it.

The bad housing of the library continues to be the most obvious and distressing of its problems. The progressive deterioration of its fine collections caused by overcrowding and lack of funds for binding is deplorable, while the inadequacies of its reading and reference rooms, the scattered and inconvenient locations of its shelves and stack rooms, and the absence of proper work rooms for the staff, all make its service to the Institution increasingly difficult.

SUMMARIZED STATISTICS

Accessions

	Volumes	Total recorded volumes June 30, 1947
Astrophysical Observatory (including Radiation and Organisms).....	323	12, 243
Bureau of American Ethnology.....	148	34, 462
Freer Gallery of Art.....	430	22, 127
National Collection of Fine Arts.....	405	10, 974
National Museum.....	2, 851	239, 167
National Zoological Park.....	24	4, 166
Smithsonian Deposit at the Library of Congress.....	1, 243	578, 673
Smithsonian Office.....	220	32, 185
Total.....	5, 644	933, 997

Neither incomplete volumes of periodicals nor separates and reprints are included in these figures.

Exchanges

New exchanges arranged----- 290

91 of these were assigned to the Smithsonian Deposit in the Library of Congress.

Specially requested publications received----- 6,812

1,056 of these were obtained to fill gaps in the Smithsonian Deposit sets.

Cataloging

Volumes and pamphlets cataloged----- 6,614

Cards added to catalogs and shelf lists----- 35,763

Periodicals

Periodical parts entered----- 16,481

Of these, 4,709 were sent to the Smithsonian Deposit.

Circulation

Loans of books and periodicals----- 9,534

This figure does not include the intramural circulation of books and periodicals filed in 31 sectional libraries, of which no count is kept.

Binding

Volumes sent to the bindery----- 616

Volumes repaired in the Museum----- 1,057

Respectfully submitted.

LEILA F. CLARK, *Librarian.*

Dr. ALEXANDER WETMORE,

Secretary, Smithsonian Institution.

APPENDIX 12

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches during the year ended June 30, 1947.

The Institution published during the year 26 papers in the Smithsonian Miscellaneous Collections, 1 Annual Report of the Board of Regents and pamphlet copies of 22 articles in the report appendix, 1 Annual Report of the Secretary, and 3 special publications.

The United States National Museum issued 1 Annual Report, 8 Proceedings papers, 3 Bulletins, and 2 separate papers in the bulletin series, Contributions from the United States National Herbarium.

The Bureau of American Ethnology issued 1 Annual Report and 1 Publication of the Institute of Social Anthropology.

The Freer Gallery issued 1 pamphlet, 1 paper in its Oriental Studies series, and 1 paper in its Occasional Papers series.

Of the publications there were distributed 158,129 copies, which included 35 volumes and separates of Smithsonian Contributions to Knowledge, 50,353 volumes and separates of Smithsonian Miscellaneous Collections, 20,880 volumes and separates of Smithsonian Annual Reports, 9,008 War Background Studies, 23,235 Smithsonian special publications, 22 reports on the Harriman Alaska Expedition, 34,952 volumes and separates of National Museum publications, 7,948 publications of the Bureau of American Ethnology, 257 publications of the Institute of Social Anthropology, 5 catalogs of the National Collection of Fine Arts, 2,561 volumes and pamphlets of the Freer Gallery of Art, 20 Annals of the Astrophysical Observatory, 374 reports of the American Historical Association, and 8,479 miscellaneous publications not printed by the Smithsonian Institution (mostly Survival Manuals).

SMITHSONIAN MISCELLANEOUS COLLECTIONS

In this series there were issued 1 paper and title page and table of contents in volume 104, whole volume 105, 18 papers and title page and table of contents in volume 106, and 6 papers in volume 107, as follows:

VOLUME 104

No. 23 (end of volume). The Cedartown, Georgia, meteorite, by Stuart H. Perry. 3 pp., 4 pls. (Publ. 3844.) Aug. 1, 1946.

Title page and table of contents. (Publ. 3891.) Feb. 11, 1947.

VOLUME 105

World Weather Records, 1931-1940, by H. Helm Clayton and Frances L. Clayton. x+646 pp. (Publ. 3803.) Apr. 4, 1947.

VOLUME 106

No. 1. The birds of San José and Pedro González Islands, Republic of Panamá, by Alexander Wetmore. 60 pp., 4 pls. (Publ. 3845.) Aug. 5, 1936.

No. 2. The vegetation of San José Island, Republic of Panamá, by C. O. Erlanson. 12 pp., 2 pls., 1 fig. (Publ. 3846.) July 18, 1946.

No. 5. Echinoderms from the Pearl Islands, Bay of Panamá, with a revision of the genus *Encope*, by Austin H. Clark. 11 pp., 4 pls. (Publ. 3849.) July 18, 1946.

No. 6. The nonmarine mollusks of San José Island, with notes on those of Pedro González Island, Pearl Islands, Panamá, by J. P. E. Morrison. 49 pp., 3 pls. (Publ. 3850.) Sept. 12, 1946.

No. 7. Mammals of San José Island, Bay of Panamá, by Remington Kellogg. 4 pp. (Publ. 3851.) July 18, 1946.

No. 8. Turtles collected by the Smithsonian Biological Survey of the Panama Canal Zone, by Karl Patterson Schmidt. 9 pp., 1 pl. (Publ. 3852.) Aug. 1, 1946.

No. 9. The species of *Platycopia* Sars (Copepoda, Calanoida), by Mildred Stratton Wilson. 16 pp., 2 figs. (Publ. 3853.) Aug. 23, 1946.

No. 10. A reexamination of the fossil human skeletal remains from Melbourne, Florida, by T. D. Stewart. 28 pp., 8 pls., 7 figs. (Publ. 3854.) Aug. 9, 1946.

No. 13. A new carnivorous dinosaur from the Lance formation of Montana, by Charles W. Gilmore. 19 pp., 4 pls. (Publ. 3857.) Sept. 12, 1946.

No. 14. A new dussumieriid fish of the genus *Jenkinsia* from Bermuda, by Luis Rene Rivas. 4 pp., 1 pl., 1 fig. (Publ. 3859.) Nov. 22, 1946.

No. 15. Ladybeetles of the genus *Epilachna* (sens. lat.) in Asia, Europe, and Australia, by G. H. Dieke. 183 pp., 27 pls. (Publ. 3860.) Jan. 20, 1947.

No. 16. New birds from Colombia, by Alexander Wetmore. 14 pp. (Publ. 3862.) Dec. 30, 1946.

No. 17. Some new Cambrian bellerophon gastropods, by J. Brookes Knight. 11 pp., 2 pls. (Publ. 3865.) Jan. 3, 1947.

No. 18. On the evolutionary significance of the Pycnogonida, by Joel W. Hedgpeth. 53 pp., 1 pl., 16 figs. (Publ. 3866.) Mar. 24, 1947.

No. 19. The lamina terminalis and preoptic recess of Amphibia, by Albert K. Reese. 9 pp., 4 pls. (Publ. 3867.) Jan. 27, 1947.

No. 20. A monograph of the West Atlantic mollusks of the family Aclididae, by Paul Bartsch. 29 pp., 6 pls. (Publ. 3868.) Feb. 24, 1947.

No. 21. Developmental physiology of the grass seedling. II. Inhibition of mesocotyl elongation in various grasses by red and by violet light, by Robert L. Weintraub and Leonard Price. 15 pp., 5 figs. (Publ. 3869.) May 8, 1947.

No. 22. Solar cycles, by H. H. Clayton. 18 pp., 9 figs. (Publ. 3870.) Mar. 5, 1947.

Title page and table of contents. (Publ. 3899.) June 11, 1947.

VOLUME 107

No. 1. The Ethnogeographic Board, by Wendell Clark Bennett. 135 pp., 2 figs. (Publ. 3889.) Apr. 14, 1947.

No. 2. The thoracic muscles of the cockroach *Periplaneta americana* (L.), by C. S. Carbonell. 23 pp., 8 pls. (Publ. 3890.) May 8, 1947.

No. 3. 1946-1947 report on the 27.0074-day cycle in Washington precipitation, by C. G. Abbot. 2 pp. (Publ. 3892.) Mar. 17, 1947.

No. 4. The sun's short regular variation and its large effect on terrestrial temperatures, by C. G. Abbot. 33 pp., 12 figs. (Publ. 3893.) Apr. 4, 1947.

No. 5. The dates and editions of Curtis' British Entomology, by Richard E. Blackwelder. 27 pp., 4 pls., 15 figs. (Publ. 3894.) June 12, 1947.

No. 6. Prehistory and the Missouri Valley development program: Summary report on the Missouri River Basin archeological survey in 1946, by Waldo R. Wedel. 17 pp., 2 pls., 1 fig. (Publ. 3895.) Apr. 23, 1947.

SMITHSONIAN ANNUAL REPORT

Report for 1945.—The complete volume of the Annual Report of the Board of Regents for 1945 was received from the Public Printer December 4, 1946:

Annual Report of the Board of Regents of the Smithsonian Institution showing the operations, expenditures, and condition of the Institution for the year ended June 30, 1945. iv+484 pp., 80 pls., 28 figs. (Publ. 3817.)

The general appendix contained the following papers (Publs. 3818-3839):

Our revolving "island universe" and its spiraling counterparts, by William T. Skilling.

Medical uses of the cyclotron, by F. G. Spear.

Drinking water from sea water, by W. V. Consolazio, N. Pace, and A. C. Ivy.

Plastics and metals—competitors or collaborators? by G. K. Scribner.

The mineral position of the United States and the outlook for the future, by Elmer W. Pehrson.

Japanese earthquakes, by N. H. Heck.

Conquest of the Northwest Passage by R. C. M. P. schooner *St. Roch*, by J. Lewis Robinson.

The New England hurricane of September 1944, by Charles F. Brooks and Conrad Chapman.

Conserving endangered wildlife species, by Hartley H. T. Jackson.

Living with the boll weevil for fifty years, by U. C. Loftin.

The indispensable honeybee, by James I. Hambleton.

The importance of plants, by William J. Robbins.

Fungi and modern affairs, by J. Ramsbottom.

The introduction of abacá (Manila hemp) into the Western Hemisphere, by H. T. Edwards.

Growing rubber in California, by E. L. Perry.

Thinking about race, by S. L. Washburn.

A unique prehistoric irrigation project, by Henry C. Shetrone.

Concepts of the sun among American Indians, by M. W. Stirling.

Human problems in military aviation, by Detlev W. Bronk.

Blood and blood derivatives, by Edwin J. Cohn.

The microbiotics, by John N. McDonnell.

A brief summary of the Smithsonian Institution's part in World War II.

Report for 1946.—The Report of the Secretary, which included the financial report of the executive committee of the Board of Regents, and which will form part of the Annual Report of the Board of Regents to Congress, was issued January 7, 1947:

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ended June 30, 1946. ix+134 pp., 2 pls. (Publ. 3864.) 1947.

The Report volume for 1946, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

The first hundred years of the Smithsonian Institution, 1846-1946, by Webster P. True. viii+64 pp., 41 pls. (Publ. C.) Aug. 10, 1946.

The Smithsonian Institution edition of etchings and drypoints by Charles W. Dahlgreen. Catalogue. 19 pp., 71 illustrations. 1946.

Classified list of Smithsonian publications available for distribution December 1, 1946, compiled by Helen Munroe. 53 pp. (Publ. 3858.) 1946.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 Annual Report, 8 Proceedings papers, 3 Bulletins, and 2 separate papers in the bulletin series, Contributions from the United States National Herbarium.

REPORTS

Report on the progress and condition of the United States National Museum for the year ended June 30, 1946. iii+113 pp. Jan. 14, 1947.

PROCEEDINGS: VOLUME 95

Title page, table of contents, list of illustrations, and index. Pp. i-viii, 615-647. Mar. 24, 1947.

VOLUME 96

No. 3200. Eight new species of chalcid-flies of the genus *Pseudaphycus* Clausen, with a key to the species, by A. B. Gahan. Pp. 311-327. Nov. 22, 1946.

No. 3201. New cerambycid beetles belonging to the tribe Disteniini from Central and South America, by W. S. Fisher. Pp. 329-333. Nov. 26, 1946.

No. 3202. *Machaeroides eothen* Matthew, the sabertooth creodont of the Bridger Eocene, by C. Lewis Gazin. Pp. 335-347, pls. 45-46. Dec. 16, 1946.

No. 3203. Review of some chalcidoid genera related to *Cerocephala* Westwood, by A. B. Gahan. Pp. 349-376, pls. 47, 48. Dec. 31, 1946.

No. 3204. A revision of the genera of mullets, fishes of the family Mugilidae, with descriptions of three new genera, by Leonard P. Schultz. Pp. 377-395, figs. 28-32. Dec. 5, 1946.

No. 3205. The phorid flies of Guam, by G. E. Bohart. Pp. 397-416, figs. 33-48. Feb. 17, 1947.

VOLUME 97

No. 3209. New cerambycid beetles belonging to the tribe Rhinotragini, by W. S. Fisher. Pp. 47-57. June 6, 1947.

BULLETINS

No. 50, part 10. Birds of North and Middle America. Families Cracidae, Tetraonidae, Phasianidae, Numididae, Meleagrididae, by Robert Ridgway and Herbert Friedmann. Pp. i-xii, 1-484, figs. 1-28. Dec. 18, 1946.

No. 191. Life histories of North American jays, crows, and titmice, by Arthur Cleveland Bent. Pp. i-xi, 1-495, pls. 1-68. Jan. 27, 1947.

No. 192. The operculate land mollusks of the family Annulariidae of the island of Hispaniola and the Bahama Archipelago, by Paul Bartsch. Pp. 1-264, pls. 1-38. Oct. 3, 1946.

CONTRIBUTIONS FROM THE UNITED STATES NATIONAL HERBARIUM

VOLUME 29

Part 3. The American species of *Hymenophyllum*, section *Sphaeroclonium*, by C. V. Morton. Pp. i-viii, 139-201. Apr. 16, 1947.

VOLUME 30

Part. 1. A botanical bibliography of the islands of the Pacific, by Elmer D. Merrill. Pp. 1-322. A subject index to Elmer D. Merrill's "A Botanical Bibliography of the Islands of the Pacific," by Egbert H. Walker. Pp. 323-404. Feb. 25, 1947.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the Bureau has continued under the immediate direction of the editor, M. Helen Palmer. During the year the following publications were issued:

Sixty-third Annual Report of the Bureau of American Ethnology, 1945-1946. 12 pp.

Institute of Social Anthropology Publ. No. 3. Moche, a Peruvian coastal community, by John Gillin. 166 pp., 26 pls., 8 figs., 1 map.

FREER GALLERY OF ART

The Freer Gallery of Art issued three publications, as follows:

The Freer Gallery of Art. 16 pp., 7 pls., 3 figs. January 1947.

A descriptive and illustrative catalog of Chinese bronzes acquired during the administration of John Ellerton Lodge, compiled by the staff of the Freer Gallery of Art. Oriental Studies, No. 3, 108 pp., frontispiece and 50 pls., 47 figs., 2 maps. (Publ. 3805.) 1946.

The Grand Empress Dowager Wên Ming and the Northern Wei Necropolis at Fang Shan, by A. G. Wenley. Occasional Papers, vol. 1, No. 1, 23 pp., 7 pls., 3 figs. (Publ. 3861.) Feb. 1, 1947.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the Association. The following report volume was issued this year.

Annual Report of the American Historical Association for 1945. Vol. 1, Proceedings and list of members. 1947.

The following were in press at the close of the fiscal year: Annual Report of the American Historical Association for 1945. Vol. 2, Spain in the Mississippi Valley, 1765-1794, pt. 1, The Revolutionary period, 1765-1781; vol. 3, Spain in the Mississippi Valley, 1765-1794, pt. 2, Postwar decade, 1782-1791; vol. 4, Spain in the Mississippi Valley, 1765-1794, pt. 3, Problems of frontier defense, 1792-1794.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Forty-ninth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, October 30, 1946.

APPROPRIATION FOR PRINTING AND BINDING

The congressional appropriation for printing and binding for the past year was entirely obligated at the close of the year. The appropriation for the coming fiscal year ending June 30, 1948, totals \$100,000, allotted as follows:

General administration (Annual Report of the Board of Regents; Annual Report of the Secretary)-----	\$18, 500
National Museum-----	41, 000
Bureau of American Ethnology-----	15, 500
National Air Museum-----	950
Editorial Division (Annual Report of the American Historical Association; blank forms)-----	13, 500
Reserve (preferably for binding)-----	10, 550
	100, 000

Respectfully submitted.

W. P. TRUE, *Chief, Editorial Division.*

Dr. A. WETMORE,

Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITH- SONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1947

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8s. 6d.—\$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de laBatut, brought the fund to the amount of \$550,000.

Since the original bequest, the Institution has received gifts from various sources, the income from which may be used for the general work of the Institution. These, including the original bequest, plus savings, are listed below, together with the income for the present year.

ENDOWMENT FUNDS

(Income for unrestricted use of the Institution)

Partly deposited in United States Treasury at 6 percent and partly invested in stocks, bonds, etc.

	Investment	Income pres- ent year
Parent fund (original Smithson bequest, plus accumulated savings).....	\$728, 876. 85	\$43, 705. 93
Subsequent bequests, gifts, etc., partly deposited in the U. S. Treasury and partly invested in the consolidated fund:		
Avery, Robert S. and Lydia, bequest fund.....	54, 019. 08	2, 409. 11
Endowment fund.....	315, 080. 70	12, 120. 32
Habel, Dr. S., bequest fund.....	500. 00	30. 00
Hachenberg, George P. and Caroline, bequest fund.....	4, 074. 69	156. 60
Hamilton, James, bequest fund.....	2, 908. 99	165. 71
Henry, Caroline, bequest fund.....	1, 225. 34	47. 07
Hodgkins, Thomas G. (general), gift.....	146, 377. 67	8, 127. 52
Porter, Henry Kirke, memorial fund.....	290, 162. 47	10, 860. 78
Rhees, William Jones, bequest fund.....	1, 069. 31	53. 79
Sanford, George H., memorial fund.....	2, 001. 92	100. 63
Witherspoon, Thomas A., memorial fund.....	130, 748. 49	5, 025. 26
Special fund, stock in reorganized closed banks.....	2, 280. 00	144. 00
Total.....	950, 448. 66	39, 240. 79
Grand total.....	1, 679, 325. 51	82, 946. 72

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These, plus accretions to date, are listed below, together with income for the present year.

	Investment	Income, present year
Abbott, William L., fund for investigations in biology.....	\$108,401.17	\$4,202.60
Arthur, James, fund for investigations and study of the sun and lecture on same.....	40,519.67	1,557.36
Bacon, Virginia Purdy, fund, for traveling scholarship to investigate fauna of countries other than the United States.....	50,760.18	1,950.95
Baird, Lucy H., fund for creating a memorial to Secretary Baird.....	24,393.69	937.56
Barstow, Frederick D., fund, for purchase of animals for Zoological Park.....	1,012.92	38.94
Canfield Collection fund for increase and care of the Canfield collection of minerals.....	38,750.42	1,489.35
Casey, Thomas L., fund, for maintenance of the Casey collection, and promotion of researches relating to Coleoptera.....	9,292.84	357.15
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks.....	28,531.11	1,096.58
Eickemeyer, Florence Brevoort, fund, for preservation and exhibition of the photographic collection of Rudolph Eickemeyer, Jr.....	513.98	19.73
Hillyer, Virgil, fund, for increase and care of Virgil Hillyer collection of lighting objects.....	6,658.71	255.91
Hitchcock, Dr. Albert S., library fund, for care of Hitchcock Agrostological Library.....	1,598.68	61.43
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air.....	100,000.00	6,000.00
Hrdlička, Aleš and Marie, fund, for further researches in physical anthropology and publication in connection therewith.....	18,633.01	716.12
Hrdlička, special.....	12,500.00	
Hughes, Bruce, fund, to found Hughes alcove.....	19,393.22	745.34
Long, Annette and Edith C., fund, for upkeep and preservation of Long collection of embroideries, laces, etc.....	550.14	21.12
Maxwell, Mary E., fund, for care, etc., of Maxwell Collection.....	9,988.40	95.98
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use and benefit of the National Collection of Fine Arts.....	19,205.20	738.12
Strong, Julia D., bequest fund, for benefit of National Collection of Fine Arts.....	10,130.05	389.32
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection.....	7,510.01	288.62
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to \$250,000.....	105,985.13	4,648.64
Rathbun, Richard, memorial fund, for use of division of U. S. National Museum containing Crustacea.....	10,775.93	414.16
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis.....	30,244.04	1,451.68
Roebbing Collection fund, for care, improvement, and increase of Roebbing collection of minerals.....	122,276.63	4,699.63
Rollins, Miriam and William, fund, for investigations in physics and chemistry.....	95,136.99	3,657.02
Smithsonian employees' retirement fund.....	80,277.80	3,085.45
Springer, Frank, fund, for care, etc., of Springer collection and library.....	18,168.84	698.28
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof.....	430,819.07	15,891.98
Younger, Helen Walcott, fund, held in trust.....	50,125.12	2,684.58
Zerbee, Frances Brinckle, fund, for endowment of aquaria.....	961.02	36.94
Total.....	1,453,113.97	58,230.54

The above funds amount to a total of \$3,132,439.48 and are carried in the following investment accounts of the Institution:

U. S. Treasury deposit account, drawing 6 percent interest.....	\$1,000,000.00
Consolidated investment fund (income in table below).....	1,859,686.86
Real estate, mortgages, etc.....	208,771.73
Special funds, miscellaneous investments.....	52,234.83
Uninvested capital.....	11,746.06

Total..... 3,132,439.48

CONSOLIDATED FUND

This fund contains substantially all the investments of the Institution, with the exception of those of the Freer Gallery of Art; the deposit of \$1,000,000 in the United States Treasury, with guaranteed income of 6 percent; and investments in real estate and real-estate mortgages. This fund contains endowments for both unrestricted and specific use. A statement of principal and income of this fund for the last 10 years follows:

Fiscal year	Principal	Income	Per- cent- age	Fiscal year	Principal	Income	Per- cent- age
1938.....	\$867,528.50	\$34,679.64	4.00	1943.....	\$1,316,533.49	\$50,524.22	3.83
1939.....	902,801.27	30,710.53	3.40	1944.....	1,372,516.41	50,783.79	3.69
1940.....	1,081,249.25	38,673.29	3.47	1945.....	1,454,957.73	50,046.67	3.50
1941.....	1,093,301.61	41,167.38	3.76	1946.....	1,559,215.25	57,612.38	3.69
1942.....	1,270,968.45	46,701.98	3.67	1947.....	1,871,432.92	74,836.65	4.00

CONSOLIDATED FUND

Gain in investments over year 1946

Investments made from gifts and savings on income.....	\$314,400.71
Less loss on sales of securities.....	2,183.04
Total.....	312,217.67

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other Oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally in his will, probated November 6, 1919, he provided stock and securities to the estimated value of \$1,958,591.42, as an endowment fund for the operation of the Gallery.

The above fund of Mr. Freer was almost entirely represented by 20,465 shares of stock in Parke, Davis & Co. As this stock advanced in value, much of it was sold and the proceeds reinvested so that the fund now amounts to \$6,069,845.32 in a selected list of securities classified later.

The invested funds of the Freer bequest are under the following headings:

Court and grounds fund.....	\$679,970.31
Court and grounds maintenance fund.....	170,756.06
Curator fund.....	691,983.14
Residuary legacy fund.....	4,527,135.81
Total.....	6,069,845.32

Statement of principal and income for the last 10 years

Fiscal year	Principal	Income	Percent- age
1938.....	\$4,820,777.31	\$255,651.61	5.30
1939.....	5,075,976.76	212,751.78	4.19
1940.....	6,112,953.46	242,573.92	3.96
1941.....	6,030,586.91	233,079.22	3.86
1942.....	5,912,878.64	241,557.77	4.08
1943.....	5,836,772.01	216,125.07	3.70
1944.....	5,881,402.17	212,395.27	3.61
1945.....	5,864,061.73	212,552.69	3.62
1946.....	5,994,394.31	220,818.86	3.68
1947.....	6,069,845.32	242,471.02	4.00

FREER FUND

Gain during present year from sale, call of securities, etc..... \$75,451.01

SUMMARY OF ENDOWMENTS

Invested endowment for general purposes..... \$1,679,325.51
Invested endowment for specific purposes other than Freer endow-
ment 1,453,113.97

Total invested endowment other than Freer endowment.... 3,132,439.48
Freer invested endowment for specific purposes..... 6,069,845.32

Total invested endowment for all purposes..... 9,202,284.80

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum, as
authorized in the U. S. Revised Statutes, sec. 5591..... \$1,000,000.00
Investments other than Freer endowment (cost or market value at
date acquired) :
Bonds (20 different groups) \$706,418.10
Stocks (50 different groups) 1,276,348.59
Real estate and first-mortgage notes..... 137,926.73
Uninvested capital..... 11,746.06

2,132,439.48
Total investments other than Freer endowment..... 3,132,439.48
Investment of Freer endowment (cost or market
value at date acquired) :
Bonds (27 different groups) \$2,783,575.97
Stocks (53 different groups) 3,240,824.22
Real estate first-mortgage notes..... 1,000.00
Uninvested capital..... 44,445.13

6,069,845.32
Total investments..... 9,202,284.80

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING FISCAL YEAR 1947¹

Cash balance on hand June 30, 1946----- \$807,410.45

Receipts:

Cash income from various sources for general work of the Institution----- \$98,761.91

Cash gifts for general work of the Institution (for investment)----- 290,500.00

Cash gifts and contributions expendable for special scientific objects (not for investment)----- 66,150.80

Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances)----- 155,903.83

Cash capital from sale, call of securities, etc. (for investment) ----- 212,294.20

Total receipts other than Freer endowment----- 823,610.74

Cash income from Freer endowment----- 242,471.02

Cash capital from sale, call of securities, etc. (for investment) ----- 952,838.45

Total receipts from Freer endowment----- 1,195,309.47

Total ----- 2,826,330.66

Disbursements:

From funds for general work of the Institution:

Buildings—care, repairs, and alteration---- \$2,441.18

Furniture and fixtures----- 451.55

General administration----- 37,110.39

Library ----- 3,133.88

Publications (comprising preparation, printing and distribution)----- 19,186.21

Researches and explorations----- 22,682.26

85,005.47

From funds for specific use other than Freer endowment:

Investments made from gifts and from savings on income----- 312,217.67

Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds, and from cash gifts for specific use (including temporary advances) ----- 148,330.32

Reinvestment of cash capital from sale, call of securities, etc----- 195,046.45

Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased----- 3,478.27

659,072.71

¹ This statement does not include Government appropriations under the administrative charge of the Institution.

Disbursements—Continued

From Freer endowment:

Operating expenses of the Gallery, salaries, field expenses, etc.....	\$79,218.52	
Purchase of art objects.....	124,790.00	
Reinvestment of cash capital from sale, call of securities, etc.....	954,000.95	
Cost of handling securities, fee of invest- ment counsel, and accrued interest on bonds purchased.....	21,786.82	
		\$1,179,796.29
Cash balance June 30, 1947.....		902,456.19
Total.....		2,826,330.66

Included in the above receipts was cash received as royalties from sales of Smithsonian Scientific Series to the amount of \$28,539.80. This was distributed as follows:

Smithsonian Institution endowment fund.....	\$12,608.21
Smithsonian Institution emergency fund.....	3,152.05
Smithsonian Institution unrestricted fund, general.....	9,456.16
Salaries	3,323.38
	28,539.80

Included in the foregoing are expenditures for researches in pure science, publications, explorations, care, increase, and study of collections, etc., as follows:

Expended from general funds of the Institution:

Publications	\$19,186.21
Researches and explorations.....	22,682.26
	\$41,868.47

Expenditures from funds devoted to specific purposes:

Researches and explorations.....	64,917.41
Care, increase, and study of special collections.....	3,186.41
Publications.....	10,996.61
	79,100.43

Total.....		120,968.90
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The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to \$642.64.

The Institution gratefully acknowledges gifts or bequests from the following:

The Viking Fund, Inc., New York City, for Iroquois research.

Ernest N. May, for scientific exploration, particularly in the West Indies.

John A. Roebling, as a further contribution for research in radiation.

Mary E. Maxwell, for care, preservation and additions to Maxwell collection of jewelry, etc.

Miss Annie-May Hegeman, for Henry Kirke Porter Memorial Fund.

All payments are made by check, signed by the Secretary of the Institution on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later withdrawn and deposited in the United States Treasury.

The foregoing report relates only to the private funds of the Institution.

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1947:

Salaries and expenses.....	\$1, 632, 912. 00
National Zoological Park	432, 500. 00

In addition, funds were transferred from other Departments of the Government for expenditure under direction of the Smithsonian Institution:

Cooperation with the American Republics (transfer from State Department).....	\$139, 589. 00
Working fund, transferred from National Park Service, Interior Department, for archeological investigations in Missouri River Basin.....	71, 500. 00

The report of the audit of the Smithsonian private funds is given below:

SEPTEMBER 17, 1947.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,

Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1947, and certify the balances of cash on hand, including petty cash fund, June 30, 1947, to be \$904,356.19.

We have verified the records of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1947, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1947.

WILLIAM L. YAEGER,
Certified Public Accountant.

Respectfully submitted.

VANNEVAR BUSH,
CLARENCE CANNON,
Executive Committee.

GENERAL APPENDIX
TO THE
SMITHSONIAN REPORT FOR 1947

ADVERTISEMENT

The object of the **GENERAL APPENDIX** to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the Secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889, a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1947.

LARGE SUNSPOTS¹

By SETH B. NICHOLSON
Mount Wilson Observatory
Carnegie Institution of Washington

[With 2 plates]

Nearly 16,000 groups of sunspots have been recorded since 1874 when the Greenwich Observatory began to catalog the spots observed on daily photographs of the sun. These groups range in size from small clusters of tiny spots a few hundred miles in diameter to huge groups nearly 200,000 miles long, containing individual spots as large as 80,000 miles across. Many spots are seen for only a day or two before they disappear, some develop to moderate size, a few grow into groups large enough to be seen without a telescope, and a very few into huge groups like the one which was visible from March 30 to April 13, 1947.

The area of every group is given for each day in the Greenwich records, the unit of area being one-millionth of a solar hemisphere, or 1,174,000 square miles. Of the 16,000 groups observed since 1874, only 27, less than one-fifth of 1 percent, attained areas as great as 2,500 millionths of a solar hemisphere (about 3,000 million square miles). These 27 groups are listed in table 1, with their maximum areas as measured by the Greenwich Observatory or the United States Naval Observatory. The areas are given to only two figures because the irregular outline of a spot seldom permits greater accuracy. Measures by different observers of several of the groups listed differ by as much as 15 percent. Of the spots recorded before 1874, three at least were large enough to have been included in the table. One of these appeared in August 1859, at heliographic latitude 20° N.; the second in July 1860, at 26° N.; and the third in August 1860, at 24° S. All the groups listed in table 1 were conspicuous objects with the unaided eye, if the sun was dimmed sufficiently by fog, smoke, or dark glasses.

¹ Reprinted by permission, with revisions (as of September 1947), from *Astronomical Society of the Pacific Leaflet No. 207*, May 1946.

TABLE 1.—*The largest sunspot groups*

Date	Latitude	Area ¹	Date	Latitude	Area ¹
	°			°	
1892, Feb. 12.....	-28	3,000	1926, Jan. 24.....	+21	3,700
1893, Aug. 7.....	-18	2,600	1928, Sept. 27.....	-15	2,600
1894, Oct. 8.....	-12	2,500	1937, Jan. 31.....	-10	2,500
1896, Sept. 17.....	+13	2,500	1937, July 29.....	+32	2,868
1897, Jan. 9.....	-7	2,700	1937, Oct. 5.....	+9	2,700
1905, Feb. 4.....	-15	3,300	1938, Jan. 18.....	+17	3,100
1905, Mar. 8.....	+10	2,600	1938, July 15.....	-11	2,500
1905, Oct. 20.....	+14	3,000	1938, Oct. 12.....	+17	3,000
1907, Feb. 12.....	-17	2,600	1939, Sept. 1.....	-15	2,600
1907, June 20.....	-14	2,500	1939, Sept. 10.....	-15	2,500
1917, Feb. 10.....	-16	3,600	1946, Feb. 5.....	+28	4,900
1917, Aug. 10.....	+16	3,200	1946, July 26.....	+23	3,950
1920, Mar. 22.....	-5	2,700	1947, Mar. 10.....	-23	² 4,300
1925, Dec. 29.....	+23	2,900	1947, Apr. 7.....	-24	² 5,400

¹ Millionths of a solar hemisphere. To express the area in million square miles increase these figures by one-sixth.

² The large group in April 1947 was probably identical with the one in March, both being in the same region on the sun. They have been considered as one group in this article.

The great spot group of April 1947, which was the largest ever recorded, developed from some small spots first seen on February 5, 1947, at the east limb of the sun in latitude 23° S. These spots grew rapidly until by February 7 they formed a group large enough to be seen without a telescope. When, after a solar rotation, the group reappeared at the east limb on March 3, it had changed considerably, being much larger and more compact than in February. In March the group was composed primarily of one huge spot, which had apparently developed from the preceding (western) members of the February group, the following members of which had disappeared. When it reappeared on March 30 for its third transit, the huge group although breaking up had increased in area. When largest it covered more than 1 percent of the solar disk, its area being 6,300,000,000 square miles, 5,400-millionths of a solar hemisphere. On its fourth and last return the group was much smaller. The preceding part, which had always been the smaller, disappeared on May 7. The following part passed around the west limb on May 11 and did not return.

The large spot of March 1947 was the largest single spot on record with an area of 5,000,000,000 square miles, 4,300-millionths of a solar hemisphere. Before 1874, visual observers sometimes published the over-all length and breadth of a group instead of its area. From this data the area cannot be computed because the group may have been composed of several unconnected spots. A long spot group observed in September and October 1858 has been cited in several popular books on astronomy as the largest group ever recorded. H. Schwabe, a noted observer of sunspots, gave its east-west diameter as 321'3, which is equivalent to 143,000 miles or one-sixth of a solar diameter. Someone, interpreting this figure as the diameter of a huge circular spot, computed its area as one thirty-sixth that of the solar disk, or 14,000-millionths of a solar hemisphere. This figure has since been

quoted in many books as the area of the largest group on record. Actually that group was a long, narrow stream of spots with an area less than 1,000-millionths of a hemisphere.

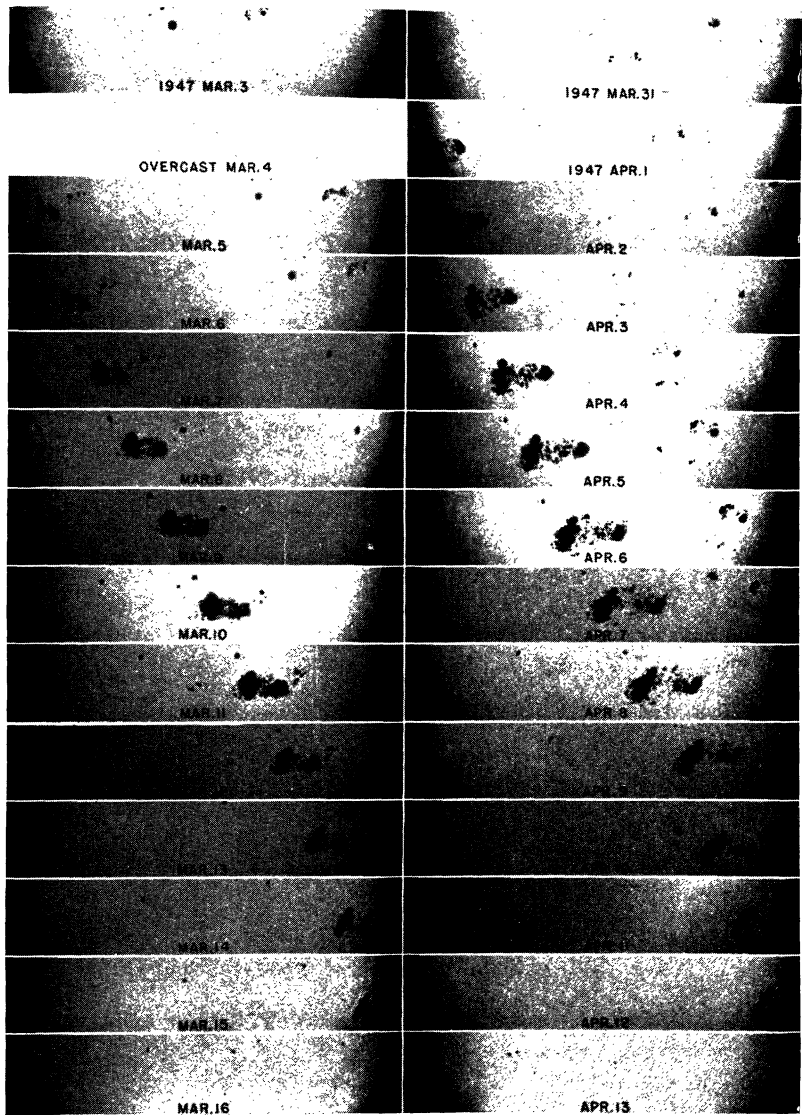
Plate 1 shows the great group of 1947 as it crossed the disk of the sun in March and April. Plate 2 shows four other large spot groups, all to the same scale. A spot group, composed of individual spots of various sizes, is usually elongated in an east-west direction. Each sunspot is composed of an irregular shaded area, sometimes nearly circular, called the penumbra, which is cooler than the sun's surface (the photosphere). Inside the penumbra are smaller, darker areas called umbrae. In large spots the umbrae cover about one-seventh of the area of the spot. Even the umbrae are not black but only less bright than the photosphere; the contrast between the photosphere and the umbra of a spot is actually less than the reproductions of the photographs would indicate. The temperature of the photosphere is about 10,000° Fahrenheit, that of the penumbra about 9,000°, and that of the umbra about 7,500°. Not all umbrae have the same temperature and the largest are not always the darkest and coolest. The radiation from the umbra of a large spot is between one-fourth and one-half that from the photosphere, from the penumbra, between two-thirds and three-fourths. In the large group of 1947, the area of all the umbrae was about 700-millionths of a solar hemisphere, that of the penumbrae about 4,700. As seen projected these areas were, respectively, 0.13 and 0.90 of 1 percent of the solar disk. The total solar radiation was therefore reduced less than one-half of 1 percent by the presence of the large spot group.

Every group listed in table 1 except those of October 1894 and September 1928, were observed for more than one solar rotation. Groups which attain their maximum area while visible are generally formed on the invisible side of the sun, and those born on the visible side are generally carried out of view before their maximum area is reached. Only 4 of the 27 largest groups were born on the visible half of the sun. Two of these, February 4, 1905, and February 12, 1907, died on the visible hemisphere; their ages were 91 days and 93 days, respectively. The group of February 1946 lasted more than 99 days; how many more is not known because it developed and disappeared on the invisible hemisphere. Smaller groups have been recorded which lasted longer than any of these. Eleven of the twenty-seven groups in table 1 returned only once, nine came back twice, and five returned three times.

A sunspot is recorded to have been observed for 18 months in 1840-41. The original record of this group has not come to my attention, but it is doubtful whether a spot or a group of spots ever retained its identity for so long a time. Although the same region on the sun may remain active for many months, the continuity of activity is usually due to a succession of spot groups. Sunspots have a habit of reappearing in

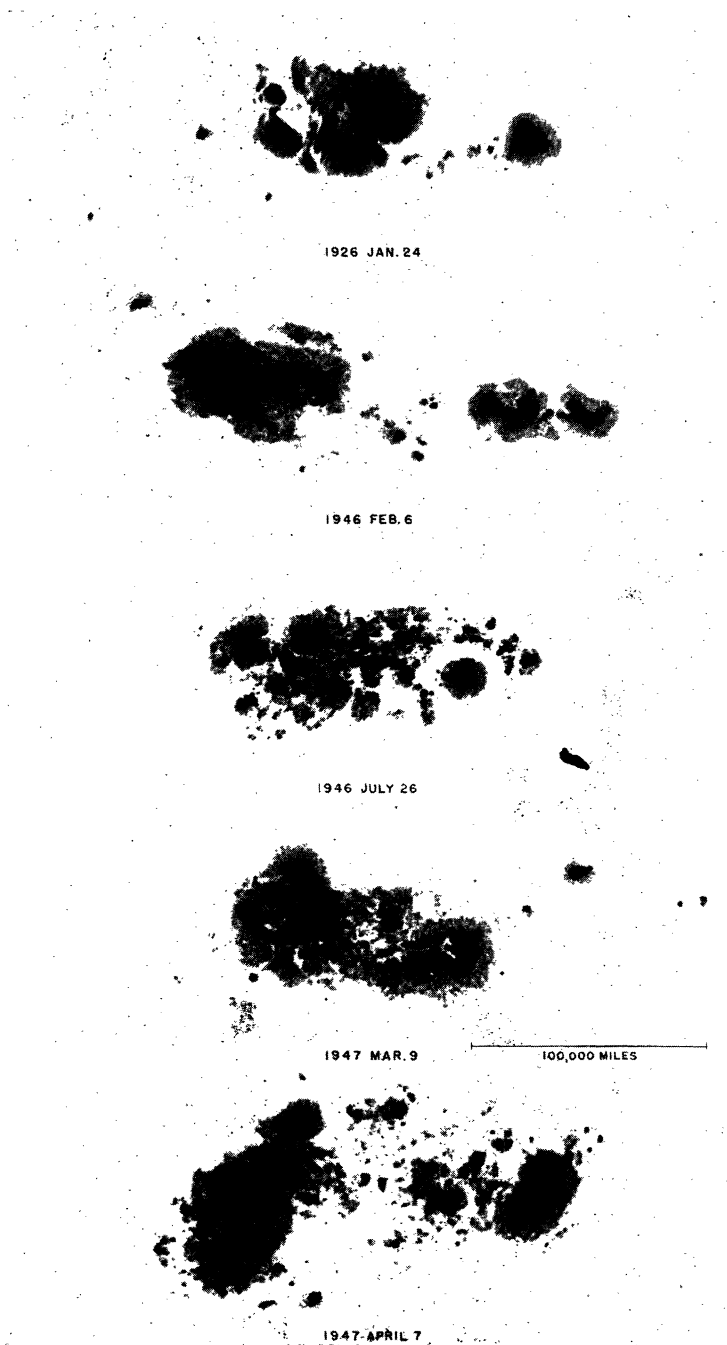
the region where an old group has been, sometimes not even waiting for the old group to disappear. The group of January 24, 1926, may have been a return of the group of December 29, 1925; certainly both were in the same region of the sun. A small round spot closely following the large group of January 1926 was probably identical with the largest spot of the December 1925 group. The large spots of the January group, however, behaved like new spots which had developed near the waning members of the December group. The two groups were therefore probably not actually identical. The groups of March and April 1947 may not be identical but their relationship seems closer than that between the groups of December 1925 and that of January 1926.

Large sunspots or, more precisely, the solar activity associated with them, definitely affect the earth. The obvious direct terrestrial effects are confined to the ionosphere, that high region of the atmosphere in which electric currents can flow and from which radio waves are reflected. The most spectacular effects are brilliant auroras (northern and southern lights). Closely associated with auroras are changes in the electric currents in the ionosphere, which produce marked fluctuations in the earth's magnetic field (magnetic storms). These disturbances can be so violent that long-distance telegraph lines and cables are affected, making communications difficult or impossible. Other terrestrial effects are produced simultaneously with very intense solar "flares," phenomena which nearly always appear in or near large spot groups. Intense flares produce minor changes in the earth's magnetic field and also cause high-frequency radio waves to be absorbed so that long-distance short-wave communication is impossible on the daytime part of the earth while a flare is in progress. These effects are in all probability due to an increase in ultraviolet radiation from the sun at the time of the flare. Although the change in solar radiation due to the presence of a large sunspot must affect the earth's lower atmosphere, and therefore the weather, such effects are very small and are difficult to measure and interpret.



THE LARGEST GROUP OF SUNSPOTS EVER PHOTOGRAPHED

Daily photographs showing the great sunspot group of March and April 1947, being carried across the solar disk by the sun's rotation.



THE FOUR LARGEST SUNSPOT GROUPS

The last two photographs are of the same group showing its development during one solar rotation

ATOMIC ENERGY¹

By A. E. JOHNS

McMaster University, Hamilton, Ontario

INTRODUCTION

Our topic for this evening is timely. Whether we are fully conscious of the fact or not and whether we like it or not, we stand at the opening of a new age—the atomic age, or the age of atomic energy. Atomic energy has always been present in the universe, but only now is it becoming available to man. The secrets of the atom are being unlocked before our eyes and life for mankind can never be the same.

Your presence here in such large numbers on such a rainy night indicates your interest in this topic. We are all interested and want to know the underlying principles of atomic energy. It is my hope that some of these will be more clear in an hour's time. But I warn you that I bring little that is new. Mark Antony's words at Caesar's funeral sum up the situation; "I am no orator, as Brutus is; * * * I only speak right on; I tell you that which you yourselves do know." The lecture will be in informal classroom style. Few teachers can proceed long without a blackboard; so I have already listed the topics I hope to treat and for two reasons. First it will help to guide me, and second it will comfort you. At any stage you can see how the lecture is progressing, and when thoroughly bored, can say "That much at least is over." You note with pleasure that the introduction is already finished.

FOUNDATION THEORY

During the eighteenth century man discovered that great law, the Law of the Conservation of Matter. According to it, no matter is ever created or destroyed. The total amount of matter in the universe remains the same. True, matter may be changed in form. Water may be heated into steam or frozen into ice, but its mass remains constant. Matter may be shifted about in the universe. The moon may lose its atmosphere or a meteorite from the bounds of the solar system may fall at our feet, but the total amount of material in the

¹ Address of the retiring president, annual At-Home of the Royal Astronomical Society of Canada at Toronto, January 24, 1947. Reprinted by permission from the *Journal of the Royal Astronomical Society of Canada*, vol. 41, No. 3, March 1947.

universe remains the same. In any chemical action the final products weigh just as much as the constituents entering it. On one scale of a balance put the coal you throw into your furnace, and pile on, if you can, all the oxygen used in combustion. On the other scale put all the ashes, and all the smoke and gases resulting from the fire. The scales balance.

In the nineteenth century was stated another great law, the Law of the Conservation of Energy. No energy is ever created or destroyed. Its form changes, its amount is unaltered. The sun's energy in the form of light and heat comes racing down to us. It dries up (at least we hope it will tomorrow) our sodden streets. The water, lifted into the clouds, has the potential energy of a raised weight. The winds carry it over Lake Erie and it falls as rain, losing some of its energy in heat, but it is still higher than the Niagara Gorge. It enters the turbines of the Ontario Hydro Electric Commission and its remaining energy is transformed into electrical energy and distributed at high voltage all over Ontario. It runs our streetcars and lights our cities. It enters our homes, runs our washing machines, our radios, our refrigerators. It cooks our meals, toasts our bread, and heats our bath water. It begins as heat, undergoes many transformations and ends up as heat. None is lost.

Nothing of him that doth fade
But doth suffer a sea-change
Into something rich and strange

The twentieth century saw the two laws combined. In 1905 Einstein propounded his theory of relativity which has revolutionized all our thinking in the scientific realm ever since. He claimed that these two conservation laws are two aspects of one more fundamental law, for matter and energy are just two manifestations of the same thing. Neither law taken alone is quite true, for matter can change into energy and energy into matter. Together they are absolute. "The total amount of matter and energy in the universe remains the same." He went further and wrote down from theory the equation

$$E=mc^2$$

connecting energy E and mass m . If m is given in grams and c is the velocity of light in centimeters per second, then E is given in ergs. Since in these units $c=3\times10^{10}$, this equation shows that a very small bit of matter will yield an enormous amount of energy. One kilogram (2.2 pounds) of matter, whether of coal or butter, if converted entirely into energy would yield 25,000 million kilowatt hours of energy; thus

$$E=\frac{1000\times9\times10^{20}}{10^7\times3600\times10^3}=25\times10^9.$$

This is equal to the energy that would be generated by the total electric power industry in the United States (as of 1939) running for approximately 2 months. Burning this amount of coal would give us 8.5 kilowatt hours of heat energy, so that the ratio is about 3,000 million to 1. No wonder the tiny losses of matter could not be detected, and there was no confirmation of Einstein's prediction for 25 years, though he had suggested that radioactive substances should give it.

THEORY OF ATOMIC STRUCTURE

If we are to understand how atomic energy is released we must know something of atomic structure, and form some picture or construct some model of an atom. At dinner tonight Mrs. Johns remarked that the Chinese thought in pictures for theirs is a picture language. One woman under a roof is their ideogram for peace. That picture appeals to us; fundamentally we are all alike. Our models of the atom may not be wholly correct, but if they help our thinking, their creation is justified. We believe now that all atoms are in the main constructed out of three fundamental bricks, the electron, the proton, and the neutron, and from these atoms the whole universe is built up. The electron or Beta-particle is very light and exceedingly small, since 50,000 million placed side by side would stretch across a period at the end of a sentence on a printed page. It carries a unit negative charge of electricity. The proton carries a unit positive charge of electricity, is smaller in volume than the electron, but weighs 1,847 times as much. The neutron was discovered in 1932 by Chadwick in England, has a mass close to that of the proton and, as its name would indicate, carries no charge at all. This unique characteristic of neutrons delayed their discovery, prevents us from observing them directly, makes them very penetrating and so important in nuclear change.

From these three basic cosmic units, the 92 elements of chemistry are built and range from the lightest, hydrogen, to the heaviest, uranium. We conceive the atom as consisting of a central nucleus made up of an approximately equal number of protons and neutrons; and about the same number of electrons revolving as satellites around the nucleus. To be balanced electrically there must be just as many electrons carrying negative charges as protons carrying positive charges. This number is the atomic number of the atom. The total number of protons and neutrons in an atom is its atomic weight approximately and is called its mass number. Thus the hydrogen atom has 1 proton as nucleus, and 1 satellite electron. So its atomic number is 1 and its mass number 1. The helium atom has a nucleus consisting of 2 protons and 2 neutrons, and 2 satellite electrons. Its atomic num-

ber is 2 and its mass number 4. Nature's heaviest atom has 92 protons and 146 neutrons for its nucleus, and 92 satellite electrons. Its atomic number is 92 and its mass number 238. This atom turns out to be the basic source of atomic energy.

Atoms themselves are also exceedingly small, for the combined diameters of 200 million of them would be an inch long. Even at that they consist mostly of emptiness, for if the nucleus were enlarged to a baseball, the satellite electrons would be specks some 2,000 feet away. As we know, the solar system is also mostly empty. In round numbers for both the atom and the solar system the radius of the whole is 10,000 times the radius of the central sun. The analogy is striking.

The chemical properties of any substance are determined by the satellite electrons. In this sense then, chemistry is concerned only with the superstructure of the atoms, and never comes to grips with

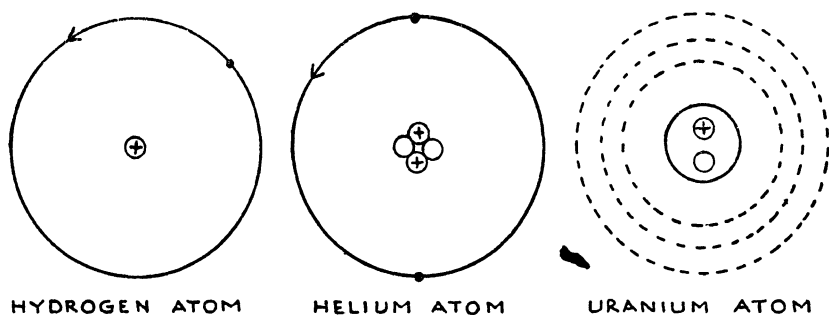


FIGURE 1.

the nucleus. The 92 elements of chemistry have the 92 kinds of superstructure. Though the satellite electrons move at high speed their mass is negligible, so that the energy values involved are relatively small and chemical changes can yield but little energy.

ISOTOPES

An architect with only 92 house elevations could design many more than 92 interiors. Similarly nature assisted by man has designed upwards of 600 atoms despite the fact that only 92 exteriors seemed possible. This is accomplished by the addition to or subtraction from the nucleus of neutrons, thus changing the mass number. These new atoms are called isotopes of the original and are chemically indistinguishable from them. Thus heavy hydrogen has 1 proton and 1 neutron in its nucleus and 1 satellite electron, so that it is almost twice as heavy as ordinary hydrogen, but has the same chemical prop-

erties. Heavy water is built up from heavy hydrogen and oxygen. It is very expensive and is used by the ton in the atomic-energy plant at Chalk River. Natural carbon consists of 99 percent of ${}^{12}_6\text{C}$ and 1 percent of ${}^{13}_6\text{C}$, the former having as nucleus 6 protons and 6 neutrons and the latter 6 protons and 7 neutrons. The respective atomic weights are 12 and 13. Both are carbon with atomic number 6. Uranium as found in nature consists of three isotopes, a trace of U^{234} with 142 neutrons, 0.7 percent of U^{235} with 143 neutrons, and 99.3 percent of U^{238} with 146 neutrons. It turns out that the valuable one for securing the release of atomic energy is U^{235} , but it is found mixed with 139 parts of U^{238} . If the proportion in nature had been reversed, the Germans would have won the war.

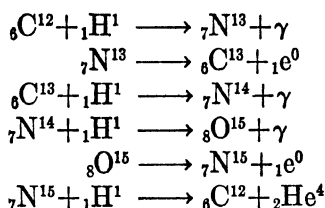
ATOMIC ENERGY RELEASED BY NATURE

We have seen that chemical actions, which are always concerned with the superstructure of the atom, yield comparatively little energy. To secure larger amounts the nucleus of the atom must be invaded. I shall cite two illustrations of such energy release which is going on in nature.

The first is radioactivity. It has been known for about 50 years that the element radium is continuously shooting out projectiles at terrific speeds. Such emanations are of three types, α -particles which are the nuclei of helium atoms, β -particles or electrons, and γ -rays which are similar to X-rays. By a series of transformations an atom of radium, ${}_{88}\text{Ra}^{226}$, with mass number 226 and atomic number 88 gives off, besides γ -rays, five α -particles and four β -particles to become an atom of lead, ${}_{82}\text{Pb}^{206}$, with mass number 206 and atomic number 82. The mass numbers check, since each helium atom has a mass number of 4 and $5 \times 4 = 20$ is the loss in mass number. The atomic numbers also check, since $5 \times 2 = 10$ units of positive charge are lost with the five α -particles, and four unit negative charges with the four electrons—a net loss of six units of positive charge from the nucleus. Radium is being transformed into lead before our eyes. In about 1,600 years half our radium will be so transformed. In another 1,600 years half of what remained, and so on. Hence we speak of the half-life of radium as 1,600 years. Always some radium will remain.

Our second illustration is of special interest to the astronomer. We are told that the sun in every second of time is giving out 10^{20} kilowatt hours of energy and has been doing this for some 10^9 or 10^{10} years. Using Einstein's equation $E=mc^2$, we find that this is equivalent to the transformation of 250 million tons of matter into energy every minute over this tremendous span of time. Professor

Bethe of Cornell suggests that the source of this energy is atomic and gives us the following "carbon cycle" of nuclear reactions.



In this cycle enter one isotope of oxygen, three of nitrogen, and two of carbon. The net result of the cycle is to leave the carbon unchanged, emit three γ -rays and two positrons, ${}_1\text{e}^0$ (the counterpart of the electron with a unit positive charge), and convert four atoms of hydrogen into one atom of helium. Now the mass of four atoms of hydrogen is 4.032 units while that of one atom of helium is 4.004. The difference of 0.028 units, which amounts to about $\frac{7}{10}$ of 1 percent of the original, has been transformed into energy. The late Sir James Jeans made this statement, "A sun in which only $\frac{1}{5}$ of 1 percent. was hydrogen could provide the present sun's radiation for 2,000 million years, and it is fairly certain that the sun contains more hydrogen than this."²

ATOMIC ENERGY RELEASED BY MAN—FISSION

For the splitting of an atom man has at his disposal some very high-power projectiles in the form of neutrons, deuterons, protons, α -particles, γ -rays, and rarely heavy particles. It is difficult to hit the nucleus of an atom with a charged particle, since either the sheltering cloud of electrons or the repulsive force of the nucleus will turn the missile aside. But neutrons, having no charge, can be deflected only by a direct collision and so are most effective as atom smashers. Using neutrons, men began bombarding all the elements, and it was found that in general the nucleus absorbed the neutron, achieved stability by emitting an electron, and formed a nucleus with atomic number and mass number each one higher than the original. It was natural to investigate what would happen when uranium, the heaviest element, was bombarded with neutrons. Late in 1938 O. Hahn of Germany (who in 1945 was given the Nobel Prize), showed that the heavy uranium nucleus was broken and that one of the fission products

² For details I commend to you the book "Atomic Artillery and the Atomic Bomb," written by my old friend and classmate, Prof. J. K. Robertson of Queen's University. I am indebted to him for some of these ideas and even some of the phrasing.

was barium. Extensive experiments in both Europe and America had by June 1939 confirmed this atomic fission.³ Here I only mention three of the many then known facts, but will amplify them later.

(1) The products of the atomic fission were two unequal fragments near the middle of the table of atoms, for example, barium and krypton.

(2) Tremendous amounts of energy were given off in the process.

(3) From each atomic fission caused by one neutron, one to three neutrons arose.

Graphically the fission may be indicated thus:

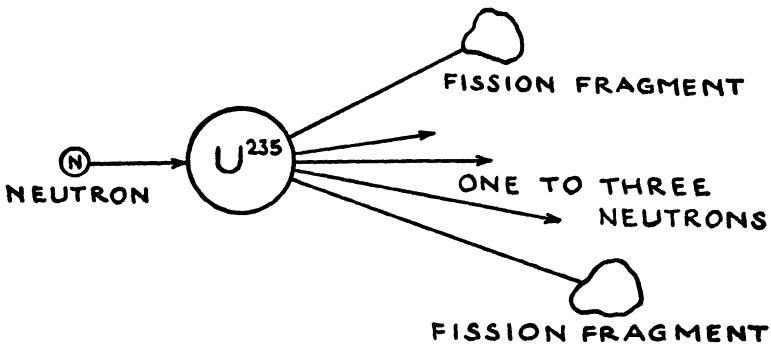


FIGURE 2.

Here then was something new under the sun. Atomic fission was a fact. The atom had been split. Then the black curtain of war descended on the world and split the scientists also into isolated groups.

THE MASS-DEFECT CURVE—BINDING ENERGY

Let us return for a moment to the two illustrations cited of the release of atomic energy in nature, namely, radioactivity and the carbon cycle. It seems remarkable that energy can be released either by the breaking down of the more complex radium atom to the less complex lead atom or by the building up of the more complex helium atom from the less complex hydrogen atom. That both processes yield energy is possible because of the nature of the 92 elements themselves. It is a fact that the mass per particle (neutron or proton) in the nucleus is greater for either the very light or the very heavy elements than it is for the elements midway between. Hence when hydrogen is transformed to helium or uranium to barium, mass is lost, and

³For details I commend to your study Smyth's book, "Atomic Energy for Military Purposes."

it appears as energy released. A graphic picture of what happens may be made thus:

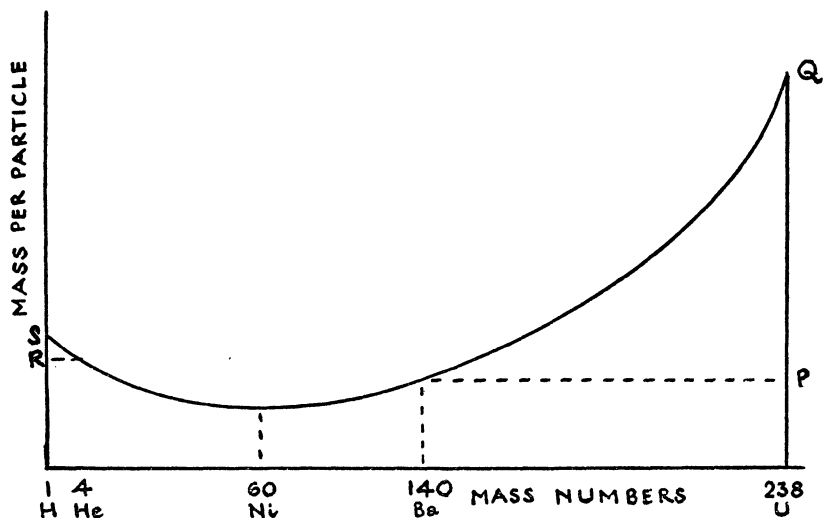


FIGURE 3.

The mass lost in the change from uranium to barium represented by PQ is 100 times the mass lost in the change from hydrogen to helium represented by RS.

The same facts may be stated in terms of energy. The "binding energy" of a nucleus is defined to be the difference between the sum of the masses of all the protons and neutrons which went into its composition and the true nuclear mass. Thus the elements in the middle of the periodic table have the greatest binding energy or are most strongly bound. To break them up energy would have to be supplied; but when atoms of elements near either end of the table are transformed energy is released.

A CHAIN REACTION

Ordinary combustion is an illustration of a chain reaction. We light a match. It sets fire to some paper. This ignites the kindling next it. This in turn, we hope, will ignite the coal. It is self-sustaining. The fact that more than one neutron came out as a fission product, when only one caused the fission of U^{235} , suggested the possibility of a chain reaction, but no one knew whether or not it would work. If from 1 neutron came 3, from 3, 9, from 9, 27, the reaction would expand at a terrific rate. But it should be remembered that it is the rare isotope U^{235} which is broken by the neutron, and this occurs in nature mixed with 139 times as much U^{238} . So at least four things could happen to the emitted neutrons. They might (1) escape, (2) be

captured by U^{238} without fission, (3) be absorbed by impurities, (4) cause fission of another U^{235} nucleus. To get a chain reaction the number of neutrons in (4) decreased by the sum of those in (1), (2), and (3) must at least equal the original number put in. The first three possibilities must then be reduced to a minimum. The first loss was easily handled by making the pile of uranium being treated large enough. When the edge of a cube is tripled in length, the surface is increased ninefold, but the volume is increased twenty-sevenfold. So the chance of escape through the surface per unit volume is much less than it was before. From theoretical considerations Fermi calculated how large, under attainable conditions, the pile should be and it worked—a marvelous achievement. Losses (2) and (3) were much more difficult to reduce to a minimum. Only the tremendous resources of the United States could make possible their solution, and a billion-dollar plant was built at Oak Ridge, Tenn. Since U^{235} and U^{238} are chemically indistinguishable they must be separated by physical means from the fact that U^{238} is the slightly heavier of the two. Thermal diffusion would separate the lighter fluid, U^{235} , just as our mothers got the lighter Devonshire cream on a pan of milk. Gaseous diffusion through barriers allowed the lighter U^{235} gas to pass more readily. The cream-separator trick of the centrifuge brought the lighter U^{235} to the center and a huge electromagnet could deflect lighter ions more than the heavier ones. Since some substances, for example cadmium, soak up neutrons like a sponge, the problem of obtaining pure materials was also a formidable one. However, these difficulties were sufficiently overcome and a pile was built in the squash court in Stagg Field at the University of Chicago. Cadmium rods were inserted as safety devices and on December 2, 1942, the first self-maintaining nuclear chain reaction was initiated by man, even with the cadmium rods only partly withdrawn. For the well-being of Chicago the pile was torn down and moved to the Argonne Woods, some 40 miles outside Chicago. It should be noted that there are always enough stray neutrons about to start the chain reaction, so that no “match” is required.

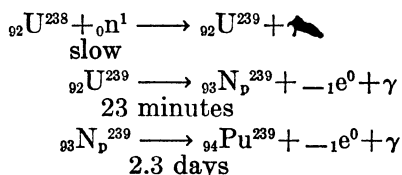
MODERATORS

It was early suggested by Fermi, Compton, and others that slow neutrons, that is thermal or low-energy neutrons, could be used to split U^{235} and that such might not be absorbed by U^{238} . Since the neutrons coming out of the fission are always moving at high speed, a search was begun for so-called moderators which would slow up such neutrons before they were absorbed by U^{238} . If such could be found, the separation of U^{235} from U^{238} might not be necessary. Now fast neutrons are hard to stop, for they can pierce several inches of steel

and about 3 feet of concrete, and yet the only way to stop them is to put something in their way. A tennis ball rebounds from the hard court with its velocity only slightly lessened, but if it collides head on with another tennis ball, its energy is passed on to the other and it stops dead. At each collision with a ball heavier than itself part of its energy would be given up. So moderators must have nuclei with masses comparable to the mass of the neutron, if the neutron is to be slowed up at each collision. Also to be useful it must itself not absorb neutrons. The substances with both these characteristics turned out to be carbon and heavy water, and both had to be of high purity. In the first pile at Chicago carbon was used, while at Chalk River heavy water is the moderator. This heavy water was made at Trail, British Columbia, tested at McMaster University, and used at Chalk River.

MAN-MADE ELEMENTS

When a slow neutron is absorbed by a nucleus of U^{238} , a nucleus of an unstable isotope, U^{239} , is formed. Its half-life is only 23 minutes and from its disintegration a new element, neptunium, with atomic number 93 and mass number 239 is formed. This new element also is unstable with a half-life of 2.3 days and disintegrates to form a second new element, plutonium, with atomic number 94 and mass number 239. The reactions are



This isotope ${}_{94}Pu^{239}$ of plutonium does slowly decay by the emission of an α -particle to ${}_{92}U^{235}$, but its half-life is 24,000 years, so that it is really very stable. Recently the discovery of two more man-made elements has been announced. Since the astronomers in their search of planets beyond Pluto have not kept pace with the discovery of elements beyond plutonium, it is proposed to call these two elements americium and curium respectively, in honor of the Americas and of Pierre and Marie Curie.

Plutonium has qualities which make it so tremendously important that it is largely replacing U^{235} in both military and peacetime applications. Though usually stable, it is fissionable by slow neutrons just as U^{235} . It is potentially more abundant since it is created from the much more plentiful U^{238} . It is a different element from uranium and hence can be separated from it by chemical means. So the atomic-energy plant using uranium is allowed to

run several months, after which the uranium rods are removed and the plutonium created in them is separated out. It is like hunting a needle in a haystack, for 50 kilograms of uranium may have 10 grams of plutonium in it.

FISSION PRODUCTS

I have already remarked that the kinds of atoms now discovered number upwards of 600, and of these a very large number, well over 200, have arisen as fission products by neutron bombardment of uranium. These fission products range all the way from zinc to samarium. Strangely enough they break into two groups. The light group consists of those from zinc with mass number about 72 to palladium with mass number about 108, and shows the greatest concentration around krypton with mass number 94. The heavy group goes from palladium to samarium with mass number 150 and shows the greatest concentration around barium with mass number 140. Actually about 6 percent is krypton and 6 percent barium, with 97 percent of all fission products grouped closely around these. The minimum is around tin with mass number 117 and the yield there is about 0.01 percent of the whole.

For the lighter elements in the periodic table the number of neutrons in the nucleus is about equal to the number of protons. For instance carbon has 6 of each. But as we ascend in the table the proportion of neutrons to protons gradually increases until in uranium 238 there are 146 neutrons to 92 protons. So the fission products from uranium, which are near the middle of the table, are overloaded with neutrons and are likely to be unstable and give off beta-rays in succession until a stable product is formed. There are 64 such mass chains of transformations now known, 31 in the light group and 33 in the heavy, and they involve about 164 known active products, and about 64 stable ones. McMaster University, under Dr. Thode's direction, is given credit for the discovery of eight of the stable products, and one active one, namely, Kr^{85} with a half-life of 10 years.

The problems presented to the chemist by these fission products were appalling. He had to separate the minute quantities of these bewildering products from the original uranium and the neptunium and plutonium created there as well. He had to determine what elements were there and what isotope. If the product was radioactive, what was its half-life; was it formed directly or was it part of a chain; and if of a chain, how was it related to other fission products? What energy had the β - and γ -rays emitted? These and many other questions confronted the chemist, and he had to work with exceedingly minute quantities and he had to work fast. Any product with half-life of less than 2 seconds cannot yet be identified. One instrument,

the mass spectrometer, has been his powerful ally. By it he "scans" the fission products and obtains results of surprising accuracy.

INDUSTRIAL APPLICATIONS OF ATOMIC ENERGY

The energy released in atomic fission is tremendous. From the smashing of a single uranium nucleus come some 160 million electron volts. (An electron volt is the energy acquired by an electron in moving through a potential difference of 1 volt.) Chemical action might yield 2 or 3 electron volts. The fission of 1 pound of U^{235} would yield 11,400,000 kilowatt hours of energy.

Is it any wonder then that an atomic bomb can do such terrible damage? At 8.17 a. m. on August 5, 1945, there was a blinding flash in Hiroshima—a piece of the sun instantaneously created. All buildings within a radius of 2 miles were completely destroyed, roofs were off at 5 miles, and glass broken 12 miles away; 95,000 people were killed or missing, and 140,000 more injured. Of 600 girls from a Protestant girls' school who were scattered over the city, 30 to 40 later returned. The falling roof pinned 50 of those at school under it and they were burned before the eyes of their principal. Such a bomb dropped on the campus of the University of Toronto would wipe out everything from St. Clair to the Lake, and from the Don halfway to High Park, and glass would be broken in Port Credit. In a twinkling one-quarter of the population of Greater Toronto would be killed or injured. And now they can make bombs 1,000 times as powerful as that.

But atomic energy could be and we trust will be a marvelous blessing. Already estimates would indicate that atomic-energy plants can deliver energy at 0.8 cents per kilowatt hour. (We pay 0.7 cents for domestic use in Hamilton.) We cannot expect it to power our automobiles. The critical size of a pile to get any power at all, and the tons of steel and concrete necessary to protect us from those penetrating radiations, prevent us from just putting a gram of plutonium in our car and running it for a lifetime. But such a pile could power an Atlantic liner, and it could provide power in parts of the world where there is neither coal nor hydro.

Recently at McMaster I heard a fine address on Canadian Population Trends by an authority. In all his prognosis the speaker was careful to put in a qualifying "all conditions being the same." I recalled a jocular remark made in an after-dinner speech by my old professor, the late Alfred Baker. "It is customary for great men at some time in their lives to make a prophecy. I will make mine now. I predict that in 500 years the center of civilization will be in the Saskatchewan Valley." So in the question period I asked the speaker if that were possible. He did not think so. Industrial concentration was unlikely in a land where there was no iron and only poor-grade

coal. Dr. Thode then rose to say that conditions were not the same. The atomic age had arrived. Power plants can as well be built in Saskatchewan as in Hamilton. Who can predict the industrial future of our Canadian West in this new age?

ATOMIC ENERGY IN MEDICINE

It was recognized at once that the wealth of radioactive fission products made available in quantity by atomic-energy plants had opened up great new possibilities in medicine. The half-life of some of these is long enough to make them useful. Phosphorus, P^{32} , has a half-life of 14.3 days. Iodine, I^{131} , has a half-life of 8 days. Treatment by radium may be completely superseded by the use of such new products as these.

They can be used as tracers. Radioactive sodium, Na^{24} , injected into the blood stream in one hand reaches the other hand in 20 seconds. If taken internally it reaches the finger tips in 2 or 3 minutes. Radioactive carbon, C^{14} , may help us to understand the whole process of metabolism. Some scientists claim that its production may well be worth all the money spent on atomic fission. Its half-life is about 10,000 years.

Iodine, I^{131} , if taken into the human system heads for the thyroid gland, as does ordinary iodine. Can cancer of the thyroid be cured by letting iodine, I^{131} , seek out its prey? Radioactive phosphorus, P^{32} , concentrates in the spleen and liver, so that large doses can be given these organs. Already this isotope has given spectacular results in the treatment of polythemia vera, a sort of cancer of the red corpuscles. But here, as always, must follow an immense amount of investigation of just how each fission product acts on human tissue, what human enemy does it attack, and what is the proper dose that will kill this enemy and not unduly injure healthy tissue. We are just entering the Promised Land—the Atomic Energy Age.

CHALK RIVER

I had hoped to speak briefly on our Canadian atomic-energy plant at Chalk River, which I visited last summer. However, this lecture is already too long so that my remarks on this topic must be very sketchy.

This site, halfway between North Bay and Ottawa, on the Ottawa River, was chosen because it had three main qualifications. It had an ample supply of pure water, it was accessible for bringing in heavy machinery, and it was not near large centers of population in case of accident. In less than 3 years huge buildings have been erected and these are carefully guarded. In order to gain entrance,

one has to lay plans some weeks in advance, be finger-printed, have his past history checked, and declare that he will not sell out to the enemy. Inside is the sign, "What you see here, what you hear here, stays here when you leave here." In some respects it is almost like a university, for there were lectures almost daily, as each department tried to keep the others informed of its latest discovery. Everywhere the greatest precautions are taken for safeguarding the health of the workers and visitors. In certain buildings cloth shoes and coats are provided, to insure that we did not inadvertently pick up some radioactive particle, which might cause a burn. The chemists watched their experiments through periscopes. No work is being done on atomic bombs, but important investigations in industrial and medical applications of atomic energy are under way. I found it a stimulating, almost an exciting place, to visit.

The workers at the Chalk River plant are housed in a town site, Deep River, 12 miles by bus up the Ottawa River. This, too, had a guardhouse at its entrance. Three years ago the site was just sand with a light stand of evergreen and birch. Bulldozers ripped out the streets, sidewalks went down, some 400 houses went up, and now behold a town of some 2,000 people. A staff house shelters and feeds about 200 workers and guests. There is a general store, a five-room public school, a hospital with plenty of maternity cases, a recreation center, and a church being organized. Some 20 clubs, camera, chess, skiing, etc., flourish. It is a young people's town. The number of academic degrees held by its inhabitants per capita is probably the highest in Canada.

CONCLUSION

I conclude with the following quotation from the Presidential Address to the British Association delivered in 1934 by the late Sir James Jeans:

Science has given man control over nature before he has gained control over himself. The tragedy does not lie in man having so much scientific control over nature, but in his having so little control over himself. Human nature changes very slowly and so forever lags behind human knowledge which accumulates very rapidly. Scientific knowledge is transmitted from one generation to another while acquired characteristics are not. Thus in respect of knowledge each generation stands on the shoulders of its predecessor but in respect of human nature both stand on the same ground.

TELEGRAPHY—PONY EXPRESS TO BEAM RADIO :

By GEORGE C. HILLIS

*General Inspector, Western Union Telegraph Co.
New York, N. Y.*

[With 3 plates]

Inasmuch as the Western Society of Engineers is composed of many branches of the engineering profession who may not be familiar with terms used in the communications field, I shall endeavor to review the progress of written communications from the early Morse days to the recently developed microwave radio beam in what our transmission research engineer, F. B. Bramhall, likes to call "basic barnyard English."

To many people, a telegram calls to mind a mental picture of a Western Union messenger boy pedaling his bicycle down the street, or of a Morse operator copying a message by listening to the dots and dashes of a sounder. New and improved methods of operation have made strides to change this mental picture of telegraphy.

The telegraph was invented in 1832 and mechanically perfected in 1837 by Samuel F. B. Morse. The first practical telegraph instrument, as he termed it, was exhibited in his rooms at New York University. His receiver consisted of a magnetically operated pendulum mounted on a picture frame, marking on a moving paper tape. It was not until 1844 that the first public telegraph message "What hath God wrought?" was sent by Morse over the first line from Washington, D. C., to Baltimore.

The marked paper tape had to be deciphered by the receiving operator and the message written on a blank. The speed of operation depended on the ability of the sending operator and the receiving equipment and was probably less than 10 words a minute.

It took but a short time before the receiving operator found he could read the dots and dashes without having to look at the tape—translating the sound was much easier. Improvement in apparatus allowed the operator to send about 11 dots per second with a semi-automatic sending machine termed a "bug." Exceptionally good sending and receiving operators could handle an average of 100 short messages an hour.

¹ Reprinted by permission from the Journal of the Western Society of Engineers, vol. 51, No. 3, pt. 1, September 1946.

Duplex telegraphy was invented by the president of the Franklin Telegraph Co. in 1872. This allowed simultaneous sending and receiving at each end of the circuit, doubling the circuit capacity. The Western Union purchased this patent, then made arrangements with Thomas A. Edison to see if any latent possibilities could be developed.

After considerable experimenting, Mr. Edison invented the Quadruplex. This method allowed two simultaneous sendings in each direction. The single circuit capacity had now been increased four-fold.

The Wheatstone siphon recorder, an English invention, was brought to this country in 1883 and was used extensively on the earlier cable circuits. It was soon replaced on land lines by a faster type Wheatstone recorder. An inked wheel marked the dots and dashes upon a rapidly moving strip of paper. Signals from both of these systems were transmitted from perforated tape. The recorder could handle about 90 words per minute, but it was necessary to translate the tape and write the message on a blank.

During the period 1901 to 1910, many printing telegraph systems were developed. The better known were the House system which printed on a strip of paper and the Buckingham system which printed directly on a message blank.

The Barclay system was developed from Buckingham patents about 1904-05 and was the first printer to stand up under heavy traffic. It would handle about 50 words per minute but required frequent and careful adjustment of the selecting mechanism. It was soon replaced by the Morkrum-Kleinschmidt printer, an invention of Howard Krum of Chicago.

About 1912 the Western Union-developed page printer had been installed on the heavier circuits between New York and San Francisco. The first printer had a stationary carriage and movable type wheel. Later on, a type bar printer was developed which used the Baudot code system and is now being used in conjunction with the Multiplex. The present 21-A tape printer will handle 72 words per minute with average maintenance whereas the earlier printers required continual adjusting.

It was soon found that the line-wire circuit was capable of carrying signals much faster than a single operator could send them or faster than a single receiving printer could print them, clear the selecting mechanism and be ready for a second incoming signal. In order to make full use of the circuit, it was necessary to develop a method which could handle signal impulses to the full capacity of the circuit. This system is known as the Multiplex and is used throughout our system to handle the major portion of trunk-line traffic.

The Multiplex divides the use of the circuit among a number of channels. The sending distribution is by means of a...

mitting units of the different channels and turns them to the line in proper sequence. At the distant terminal they are picked up by a receiving distributor and turned to the corresponding printers. In order for the transmitter on channel 1 to send to the distant printer on channel 1, it is necessary to synchronize the sending and receiving distributors and drive them at closely regulated speeds by synchronous motors.

Alternating current for the motors is supplied by accurately regulated tuning forks. After the receiving distributor is brought in phase, an accurate phase-correction circuit is applied which will hold the receiving distributor in step with the distant sending distributor. It is not necessary to transmit a special phasing pulse as the phase-correction circuit operates from line intelligence signals. Experiments have been made in driving the sending and receiving distributors from a common frequency source and using no correction at the receiving end. Long distances between terminals has prevented the adoption of this method of maintaining synchronism because of the lack of a common power source.

The Multiplex is operated duplex, as 2, 3, or 4 channels, depending upon traffic load and circuit conditions. A standard operating speed of 66 words per minute has been adopted in order to facilitate the patching of channels between Multiplex systems.

A 4-channel system, duplexed, working at 66 words per minute, with 4 sendings at each terminal, will provide a total message capacity of 528 words per minute. This is a considerable increase from 10 words per minute of the original recorder used on the Baltimore-Washington circuit.

The Teleprinter has almost entirely replaced the Morse method as a means of operating lightly loaded circuits. Most of you are familiar with this machine which sends from a slightly modified typewriter keyboard and receives on either tape or page copy. The sending and receiving units may be operated independently or in series.

The Teleprinter uses the 5-unit code of the Multiplex with the addition of a phasing and stop pulse. The phasing pulse is necessary to start the receiving distributor with the transmitting cam and the stop pulse stops both the receiving and sending units so they will both start in phase for the next signal.

Supplementing the Multiplex and Teleprinter, we have the Varioplex, Telefax, and Photofax. The Varioplex uses the high capacity of the Multiplex system and by means of a control rack, a number of reperforator racks, as many as 36 Teleprinter subchannels may be operated over a single wire.

Telefax and Photofax are Western Union developments of the principles of facsimile. Telefax utilizes the pick-up of a reflected light beam through a photoelectric cell which translates changes of light

intensity to corresponding changes of electrical intensity as the scanning beam passes over the copy being transmitted. At the receiving end, the intelligence may be reconverted to changes of light intensity and recorded on a photographic film as a negative. After developing, a print from the film negative will give a positive of the original material from which transmission was made.

The received changes of electrical intensity may be inverted from a negative image to a positive image and recorded by a stylus on dry Teledeltos paper. This gives an immediate positive of the original photograph, message, drawing or other transmitted material without any further processing. Good photograph halftones may be made from this copy. Development of this equipment was halted by the war but our laboratories have resumed research in this method of communication.

Telefax installations in China have greatly speeded up communications in that country. Prior to Telefax, it was necessary to assign a number to each Chinese character in order to transmit a message by regular telegraph. This required that a message be coded in numbers, transmitted by standard telegraph, deciphered, and written on a blank. Transmission by Telefax gives an immediate reproduction of the original message with no chances for errors. The entire contents of a standard telegraph blank may be transmitted in a little over 2 minutes.

Outside of the commercial telegraph field, one use for this system has been in the handling of railroad train orders where accuracy in transmission is absolutely essential.

The transmission of intelligence from the various types of terminal equipment over open wire land lines has proved to be one of our greatest difficulties in the maintenance of uninterrupted service. The physical hazards of sleet, ice, fires, floods, railroad and vehicular wrecks, and tornadoes have caused our Dispatching Bureau many hours of "blood, sweat, and tears." Poor and corroded wire splices, kite tails that get tangled in the line, the boy (and, I might add, the man) with a 22 rifle, who finds insulators a tempting target, all add up to the incessant patrols by our linemen.

Interference caused by inductive coupling to power lines, lighting, and the interference induced by adjacent telegraph circuits have limited the distance over which transmission may be satisfactory without repeaters. When the signals become too badly mutilated, they may be rebuilt by regenerative repeaters, but this equipment is expensive and requires expert maintenance and adjustment.

In a grounded telegraph system such as we use extensively, a battery is applied to one end of the wire and the opposite end grounded, thus completing the circuit through the ground back to the battery.

Any disturbance to the earth potential will seriously affect operation over this type of circuit. On the morning of March 23-24, 1940, approximately 800 volts difference in earth potential was observed between New York City and Binghamton, N. Y. This means that with one of the wires grounded at Binghamton, the New York test-board attendant would see on his voltmeter connected to the New York end of the wire, not the Binghamton ground but anywhere from 0 to 800 volts of battery and varying from positive to negative. At times the maximum potential would hold steady for 30 seconds or more, decrease in intensity, then suddenly reverse potential and increase in intensity until approximately 800 volts of the opposite potential was reached. Under these conditions, telegraph signals of 160- or 240-volt potential were entirely obliterated.

Trouble is also experienced during very wet weather when a thin film of water on the glass insulators acts as a high resistance conductor and allows a small portion of the transmitted battery to leak off to ground at each telegraph pole and return to the transmitting station. Although this is a very small amount at each pole, when you have a 200-mile circuit with 40 poles per mile, 8,000 such leaks do not allow much of the transmitted signal to get through to the distant end.

When a second wire is substituted for the ground return, many of the above troubles are eliminated. This type of operation requires twice the wire facilities for the same number of circuits. One type of metallic system used by the telegraph company provides three excellent circuits from four wires.

In order to provide a more stable means of transmitting intelligence between terminals which would not be affected by the inherent hazards of grounded operation and provide a number of circuits over a pair of wires, the Western Union began experimenting with carrier operation in 1927.

The first 4-wire, amplitude-modulated carrier system was placed in service between New York City and Buffalo. While this system was a great improvement over physically grounded operation, it needed many improvements.

The B-3 system was placed in operation a short time later between New York and Chicago. This was a 4-wire, amplitude-modulated system originally designed for 20 operating channels. Channel frequencies ran from 450 cycles to 6,450 cycles with a 300-cycle channel width. Carrier current for the individual channels was provided by a Hammond generator, an adaption of the same machine that supplies the basic tones for a Hammond electric organ.

The addition of an automatic bias corrector to the channel terminals to compensate for changes in the received level, made these circuits far better than any ground return circuits for the operation of high-

speed Multiplex circuits where the line frequency reaches 66 cycles per second on certain letter combinations.

The amplitude-modulated system still had difficulties inherent in this type of operation. Any variation in the received signal strength had to be compensated for by similar changes in the relay bias circuit. Your amplitude-modulated radio suffers from the same types of interference.

Continual research by our Carrier System Development Group produced the first frequency-modulated terminal in 1937. A series of improvements led to the installation of the first type "E" carrier system between Dallas and Los Angeles in the fall of 1942. This was a two-wire system, using frequency-modulated terminals and provided one voice channel in each direction of transmission. The frequencies of the nine telegraph channels in the west-bound voice band range from 750 cycles to 3,150 cycles and the east-bound band from 4,050 cycles to 6,450 cycles.

The frequency-modulated telegraph channel will continue to deliver a perfect signal even though the input power to the receiving channel amplifier may drop to one three-hundredths of the standard value. The FM telegraph channels have continued to work without interruption when the physical wires over which they were working were so badly weather-bound by heavy fog that Morse signals could not be read between Chicago and Indianapolis. This system has also continued to work when one wire of the pair was broken and both ends lay on the ground.

The type "F" is also a two-wire system which provides two voice bands in each direction with a top frequency of 16 kilocycles. The two-wire type "G" system provides four voice bands in each direction with the top frequency of 30 kilocycles.

Nine wide-band FM channels may be placed on one voice band. These channels will carry signaling frequencies up to about 75 cycles per second. Sixteen narrow-band FM telegraph channels may also be placed on a voice band. The narrow-band channel is designed for a top frequency of about 33 cycles per second and will be largely used for Teleprinter operation.

Even with all the margin provided by FM operation, interruptions to the service were caused by weather conditions over which we had no control. Early in the spring of 1946, ice formed on the wires in the vicinity of Sidney, Nebr., until they became 3 inches in diameter. The weight of this much ice will break the wires in many places and if there is a slight wind, the ice-covered wires will start to swing and break off many poles, sometimes every pole between sections that are not extra-heavily braced.

Terminal equipment appeared satisfactory, but trouble-free transmission was required between terminals in order to render the best

possible telegraph service. Coaxial cable will provide this type of service where large numbers of circuits are required, but the cost is high and where high frequencies are used, repeaters are required at frequent intervals.

The Western Union electronic laboratory at Water Mill, Long Island, has continuously investigated the possibility of radio as a medium of transmission. Up to 1940, the use of radio was not advisable, for the frequencies used at the time did not provide the continuous 24-hour service the year around that is required for dependable telegraph circuit stability.

The concentrated development in the ultra-short-wave spectrum for radar techniques during the war disclosed that when the superhigh frequencies were propagated under line-of-sight conditions, they appeared to be quite stable. They were not affected by magnetic storms or lightning discharges so it was apparent that this method of transmission might be the solution to our problems.

Before the war, equipment was not available to construct oscillators which would generate frequencies much above 400 megacycles. Oscillator tank circuits were reduced in size until the capacity between elements in the vacuum tube was used as tank capacity and a single turn of wire for the tank inductance. The answer to generating still higher frequencies was found in a new type of tube which utilizes the speed of electron travel. Two types of tubes of this classification were used during the war for radar work. They are the Magnetron and Klystron. The Magnetron was developed by Dr. Hull in the General Electric laboratories and was improved on from time to time. Russian scientists added a bit, but it was not until about 1940 that English scientists made further improvements which enabled them to use the tube for high-frequency generation. The Klystron tube was invented by the Varian brothers at Stanford University. Either of these tubes is capable of generating frequencies up to 30,000 megacycles.

It has been found that at these high frequencies, where the wave lengths become several centimeters or less, they may be controlled in much the same manner as light. There is still a long way to go before the wave length of visible light is reached. At a frequency of 4,000 megacycles, the wave length is 7.5 centimeters or 3 inches, while invisible infrared rays have a wave length of about 0.01 centimeter in length and the wave lengths of visible light rays range from 0.00007 to 0.00004 centimeter in length.

A parabolic reflector, such as is used to concentrate the small candle-power of a tiny incandescent lamp in an automobile headlight, may also be used to concentrate the radiation of the microwaves. It is not practical in standard broadcast wave lengths, for in order to concen-

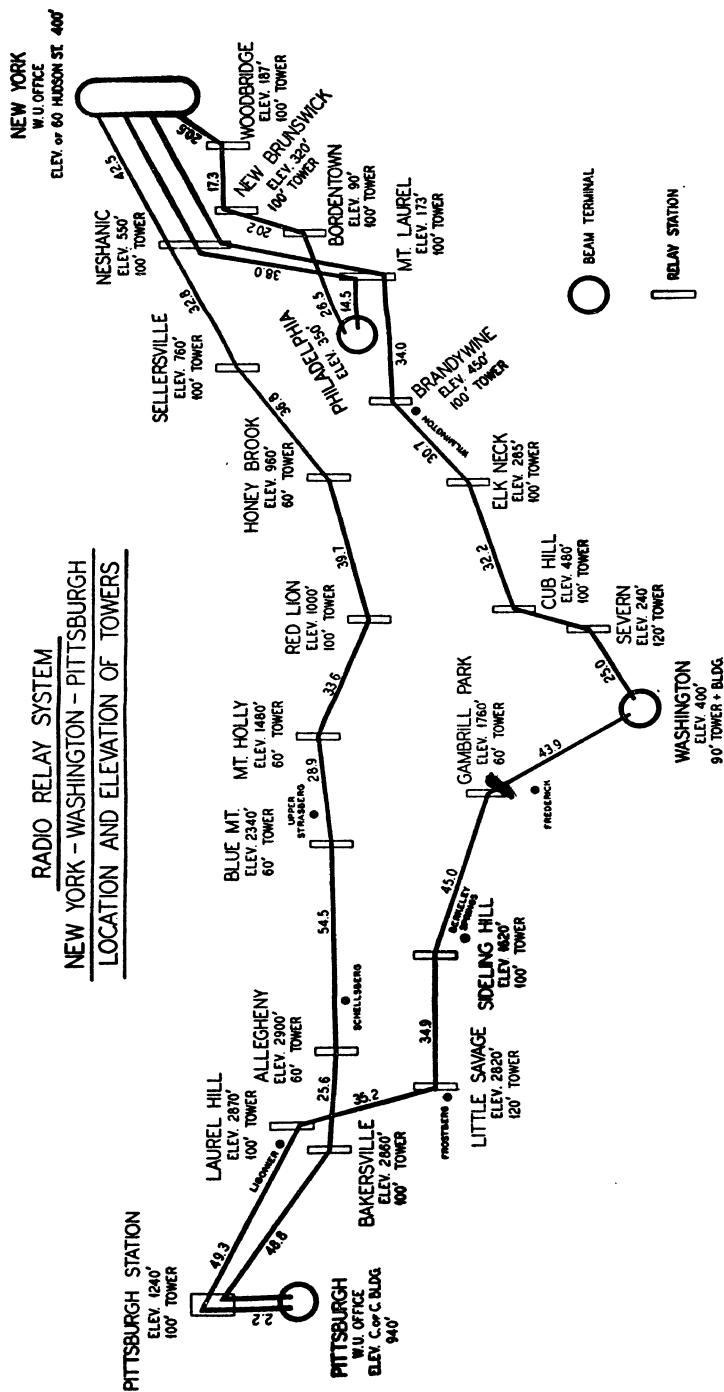


FIGURE 1.—Microwave relay system, New York-Washington-Pittsburgh.

trate the broadcast frequencies of 720 kilocycles into a beam 6° in width, it would take a parabolic reflector approximately 13,000 feet in diameter. Now to concentrate the radiation of 4,000 megacycles into the same field pattern, we would need a reflector only 30 inches in diameter.

With such a reflector, instead of letting the radio waves go off into free space in all directions, we are able to concentrate them into a beam only 6° in width, the angle being inversely proportional to the diameter of the reflector. This results in a very small field of intense radio energy at the point at which the beam is aimed. In fact, the reflector increases the energy 30 decibels, which is a gain in power of 1,000 to 1. For example, a nondirective antenna might require 1,000 watts to give the required field strength at a given point. With the parabolic reflector, only 1 watt of power would be required. If the receiving antenna is surrounded by an identical reflector, the receiver will pick up 1,000 times as much power as it would if the antenna was out in free space.

The net practical result is that radio repeater stations may be spaced about 50 miles apart and we will require only one-tenth of 1 watt of radiated power to give dependable 24-hour service, where before we would require 90 to 100 kilowatts.

The ability to concentrate the microwaves in a small space makes it possible to use the same frequency for sending or receiving from as many as eight positions at one location, or one for every 45° of the compass.

All radio waves are propagated in straight lines, microwaves included. The difference between the longer standard broadcast waves and microwaves is that when the low-frequency waves enter the ionized layers of the upper atmosphere, this refractive medium causes them to be bent and some will return to the earth. Here they are reflected upward from the ground and again refracted to appear a second time on the earth. If the sending-signal strength is great enough and the signals enter the upper atmosphere at the correct angle, they may be reflected back and forth and eventually go around the earth.

The height of the ionized layer that causes the low-frequency waves to be bent back to the earth varies continuously. The F-layer ionization decreases after sunset and reaches a minimum just before sunrise. After sunrise it splits into two distinct layers of ionization, which are termed F-1 and F-2. These layers remain separate during the day but merge into one at sunset. The average height of the F layer is about 185 miles, the F-1, 140-160 miles, and the F-2 150-250 miles. A long-wave-length signal entering these ionized regions at a constant angle will not always return to the earth at the same place as the skip distance varies as the height of the ionized layers change dur-

ing the day. The skip distance not only depends upon the time of day, but the phase of the sunspot cycle, the geographical location of the transmission path, and the season of the year. Maintaining communications by use of this medium could not be considered reliable enough for the telegraph company's use.

When the microwaves enter this ionized region of the upper atmosphere they pass through it, regardless of the angle at which they enter. This makes it necessary to transmit them parallel to the surface of the earth, catch them before they leave the earth at the horizon and retransmit them to the next tower. While the retransmission from tower to tower is more expensive than a standard broadcast which uses the ionization refraction for retransmission, it gives us a 24-hour-a-day service that the longer-wave-length frequencies can never equal in dependability.

During March 1946 there were a number of magnetic storms, some of such severity as to blank out commercial radio, halting trans-Atlantic air travel, while the microwave beam circuit showed no interference from the aurora borealis.

At this high frequency we are not bothered by any man-made or nature-made static; it is even above that of a lightning discharge.

Tests were made by having an airplane fly directly in the path of the beam. No serious deflections of the received power level were noted until the plane was about 50 feet from the reflector.

Several difficulties were encountered in developing the transmission of the microwaves when the beam was transmitted parallel to the surface of the earth. One is the absorption of energy by water vapor in the air, but this is not serious for wave lengths greater than 5 centimeters. For the shorter wave lengths, such as at 1 centimeter, a heavy rainfall will drop the receiving power level 5 decibels, which would not be noticed in FM reception, but a cloudburst along a 1-mile path of the beam will drop the received level to one-thousandth of the normal value.

A slow signal fading was noted throughout the year, but in the FM receiver this change caused no harm.

A more serious type of fading was noted in the latter part of June 1945, when in the early morning hours of a still night, especially during periods when the humidity was high, the received signal strength would fluctuate wildly. The transmitting power was increased but the results were still unsatisfactory. An investigation of the field strength at the receiving tower disclosed that the line-of-sight signal was being canceled by an out-of-phase signal. By placing a second receiving reflector between 25 and 27 feet below the upper one and using the combined output from the two reflectors, a fairly steady signal could be obtained as the fading did not appear simultaneously

at both reflectors. The resultant signal variation is well within the limits of the FM receiver and excellent results have been obtained.

The present explanation is that during periods of perfect calm there is a stratification of either temperature or humidity or both which will refract the transmitting signal causing a multipath reception at the receiving parabola.

Studies indicate that the initial installation cost and annual expense of operation of a microwave relay system will be less than that of a land line, especially if the capacity of the microwave system is fully utilized. Very little time will be required for installation of the towers and they can be moved without too much trouble. Relocating any stretch of land line is a long-drawn-out operation, with numerous interruptions to service.

These and many other advantages led the Western Union to initiate a comprehensive experimental program for the use of microwaves for commercial telegraphy. A patent license agreement was entered into with the Radio Corp. of America in July 1944 for use of the necessary radio circuit patents. Similar arrangements have also been made to use the Armstrong method of frequency modulation.

The design of the radio equipment has been rapidly developed from what were essentially radar techniques to those that will meet the requirements of telegraphy by the Victor Division of the Radio Corp. of America at Camden, N. J. The telegraph company's engineers have developed the high-capacity WN-2 carrier system which will be used in conjunction with the microwave beam system.

The Western Union carrier which feeds into the radio transmitter will consist of 32 voice channels, each of which may carry either 16 narrow-band telegraph channels, a telephone, or a facsimile circuit. The 16 narrow-band telegraph channels are in two groups of 8, each of which has a frequency spread of 525 cycles for channel 1 to 1,575 cycles for channel 8. By means of a frequency translator, identical terminal equipment is used for the second group, which, after translation in frequency, appears as a band from 2,025 cycles to 3,075 cycles. Thus the two groups fill a voice channel that has a band width of approximately 300 to 3,300 cycles. This means that only eight basic telegraph channels are required. Sixty-four duplications of each of the eight channels will be used for the entire carrier system instead of a total of 512 channel terminals, each having a different frequency. This is made possible by the frequency translator or varistor, a simple copper oxide or crystal rectifier.

The output of each of the 32 voice bands will be identical but, again by using the frequency translator, each voice band has its output translated so that they may be "stacked" one above the other in the frequency spectrum, and at the carrier system output there will be

frequencies of 525 to 150,000 cycles, all originating from eight basic channel frequencies.

The potential capacity of this system is enormous. If nine wide-band, high-speed carrier channel terminals were assigned to each of the 32 voice channels, we would have 288 channels over which we could operate the 4-channel Multiplex. This would give us 1,152 Multiplex channels, each operating at 66 words per minute, a total of 76,032 words per minute in each direction over the entire carrier system.

In case we should get both feet clear off the ground and assign a 36-channel Varioplex system to each of the 288 high-speed carrier telegraph channels, we could get 10,368 sending and receiving Teleprinter circuits for subscriber service.

If the narrow-band telegraph channel terminals were used on the 32-voice channel carrier system, we would have 512 sending and receiving positions at each terminal.

During the first stage of the modernization program, a number of 2-channel Multiplex circuits will be established between the larger offices. These will operate at 66 words per minute, or a line frequency of 33 cycles per second. In the ultimate, plans are to discontinue the use of the Multiplex with its complicated equipment and use nothing but Teleprinter circuits, as the simplicity and flexibility of this type of equipment will more than offset the high load capacity of the Multiplex.

Radio relay stations will be spaced from 20 to 50 miles apart, depending upon the topography of the land. The location will also depend upon the availability of satisfactory commercial power and will be near good roads. The height of the open steel towers will range from 60 to 120 feet, as it seems advisable that the transmitted beam clear any obstacle by 30 to 50 feet.

A small cabin 12 feet square and 9 feet high will be mounted at the top of the tower. Windows which will be transparent to the microwaves will be provided. Several materials are available for this use, such as plexiglass, laminated bakelite, but tests indicate that impregnated fiberglass cloth has the lowest loss for the high-frequency waves. Ice on an open reflector apparently does little harm, while wet snow will cause a large drop in signal strength. Provisions will be made to house a total of four reflectors with their accompanying high-frequency oscillator circuit cabinets in each tower.

A sturdily constructed concrete building about 16 by 30 feet will be located at the base of the tower. It will be heated in the winter and ventilated in the summer in order to keep the humidity as low as possible.

The balance of the radio equipment and a reserve power plant will

be located in this building. The radio equipment is designed to work from single-phase, 60-cycle commercial power. In the event of a commercial power failure, the radio load will be automatically transferred to the output of a storage-battery-driven alternator or vibrator. At the same time a gasoline-engine-driven alternator is automatically started and after the engine has reached operating speed, the radio load is transferred to this power supply and remains there until the commercial power is restored. A floating rectifier will keep the storage battery charged.

Strategically located maintenance men will service the equipment at three or four radio relay towers. They will be furnished with an automobile containing an assortment of testing equipment and spare parts, although it is planned to do most of the repair work at the maintainers headquarters.

A service channel has been provided for testing purposes between the terminals and includes all the radio relay stations. This channel is independent and does not interfere with the traffic channel.

Fault-finding equipment will be provided at the terminals so that the operating condition of each unattended tower repeater may be quickly determined. A preselected audible frequency will be sent by the terminal, which, by means of a band pass filter, will be received by the repeater station selected. This signal will be sent back to the terminal station after certain intelligence has been added and will indicate operating conditions of the equipment at that station.

Terminal towers will contain radio equipment which will translate the ultrahigh radio frequencies to the 300–150,000 cycle telegraph carrier. These frequencies are sent to the main office of the telegraph Company over a coaxial cable and by means of frequency translators and filters are separated into the 32 voice bands. The voice bands are either patched to various groups of carrier channel terminal equipment or to voice bands of other carrier systems.

Some of the terminal towers will not only contain the radio equipment, but the telegraph carrier voice band translating equipment as well. The conditions at Washington, D. C., make this arrangement more practical. At the tower, the radio frequencies will be translated to the carrier frequencies. These in turn will be broken down to the 32 voice bands and the individual voice bands transmitted over cable pairs to the main office where only the telegraph channel terminals will be located.

The radio relay network is being laid out on a triangular basis as far as possible so that with the failure of any one leg communication may be quickly reestablished by using stand-by facilities on the other two legs.

The tremendous capacity of the microwave system will be used to provide the large number of telegraph channels that will be required for our projected reperforator switching systems. The entire United States will be subdivided into 16 reperforator switching centers with each center relaying, by mechanical means, all messages in the area assigned to it. Thus, St. Louis, Mo., will relay all traffic for the State of Illinois outside of Chicago; Minneapolis will handle everything for North and South Dakota, Wisconsin, Iowa, and Minnesota. Each reperforator office will have direct circuits to every other reperforator point.

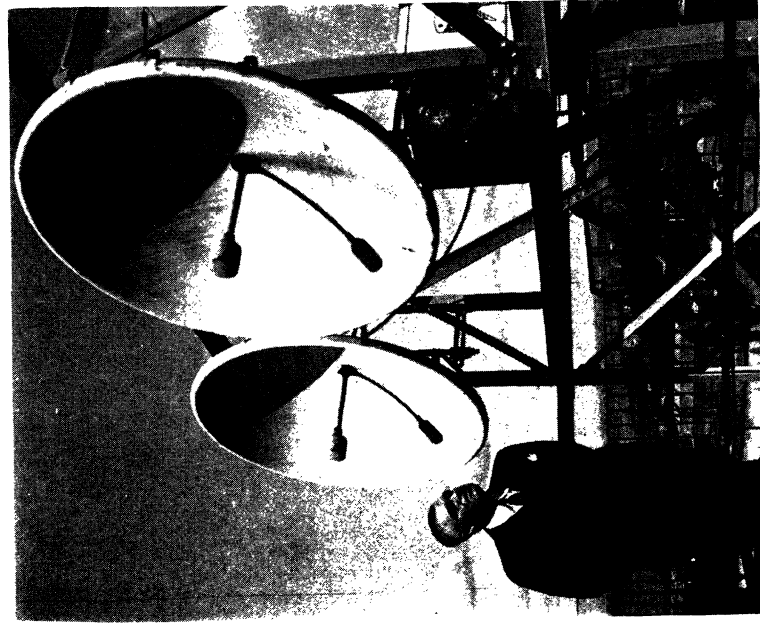
When the modernization program has been completed, a message from Portland, Maine, destined to Joliet, Ill., will be sent from Portland to Boston over a Portland-Boston feeder carrier system. At the Boston reperforation center, certain equipment will read a switching code signal, which Portland inserts ahead of every message, and will automatically switch the signals to a direct St. Louis carrier circuit. At the St. Louis reperforation center, this intelligence will be received on a printer-perforator. This device perforates the message as code in the tape and at the same time prints the message on the tape. The switching clerk notes the printer Joliet destination, presses the Joliet button. Various circuits operate to connect the associated transmitter to a Joliet circuit and start the perforated tape through the transmitter, so that within the space of a few minutes, the message will be received on a Teleprinter at Joliet. Only two switchings will be necessary to send a message from St. Petersburg, Fla., to Sacramento, Calif. The switching at the Florida area reperforation center will be entirely automatic, while the received signals at the California area reperforation center will be switched by pushing a button.

Now for the first time we can send telegrams from any independent Western Union office in the United States to any other independent office in a matter of minutes. By means of the radio relay, which will supply the multitude of circuits required, and working in conjunction with the reperforator switching systems, we will have speed and dependability that was only dreamed of a few short years ago. There will be no more worrying about ice on the wires, boys shooting insulators, kite strings in the lead, heavy wet snow and ice breaking off telegraph poles, magnetic storms, and all the other hazards of open-wire communications. Thus it can be seen that great strides have been made since the days of the Pony Express, and we are truly upon the threshold of a new era in written communications.

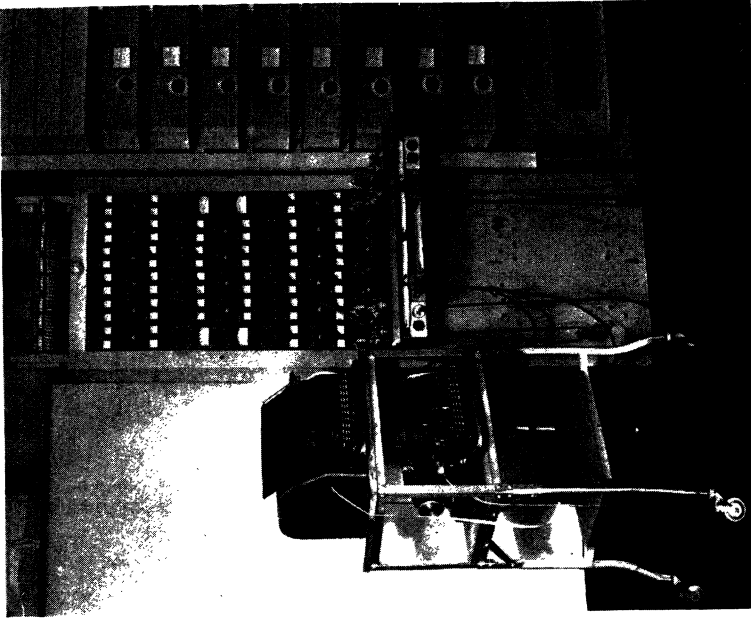
In conclusion, I wish to thank all my coworkers for the assistance they have given me and a very special "thank you" to the boys of the Carrier System Development Group in New York.

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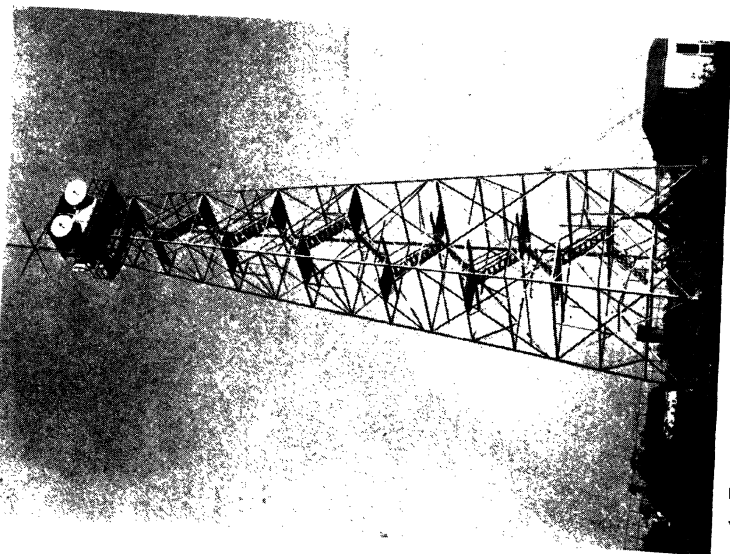
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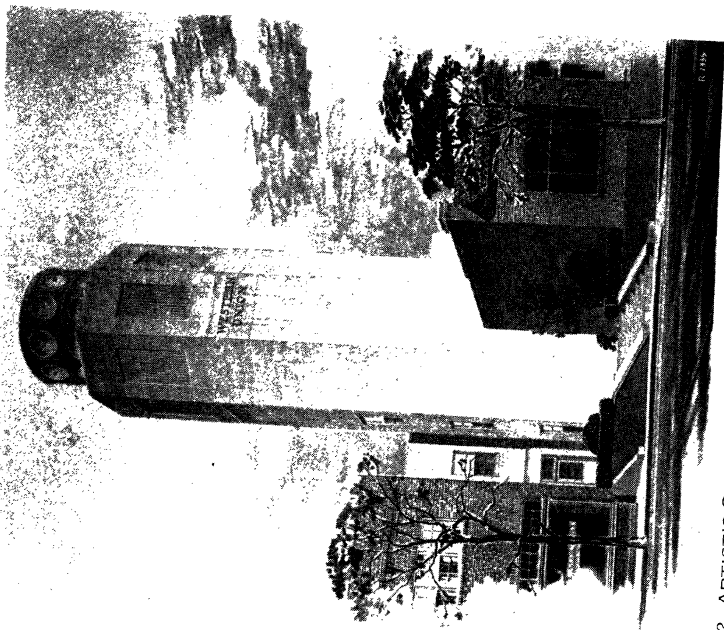
1. PARABOLIC REFLECTORS USED FOR SENDING AND RECEIVING MICROWAVES



2. CARRIER CHANNEL-TESTING EQUIPMENT



1. EXPERIMENTAL MICROWAVE RELAY TOWER



2. ARTIST'S SKETCH OF WASHINGTON, D. C., MICROWAVE RELAY TOWER



REPERFORATION CENTER SWITCHING AISLE

PLUTONIUM AND OTHER TRANSURANIUM ELEMENTS¹

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[With 1 plate]

Ever since the first classification of the elements into the periodic table arrangement, it has been felt, and as we now know, correctly, that no elements heavier than uranium exist in appreciable concentration on the earth. Since the advent of the concept of atomic number, it has been possible to state this differently—no elements with an atomic number higher than 92 are to be found in appreciable amounts. A number of searches for such elements of higher atomic number, which we may call transuranium elements, have been made, and although success in their identification has been claimed in a few cases, it is now known, with the exception of plutonium which exists in extremely small amounts as described below, that these elements do not exist in appreciable amount on the earth.

Since 1940, however, the four transuranium elements immediately following element 92 (uranium)—namely, element 93 (neptunium), element 94 (plutonium), element 95 (americium), and element 96 (curium)—have been discovered as a result of their synthesis by transmutation reactions starting with uranium as the primary material. Of these four transuranium elements, plutonium has assumed the position of dominating importance because of its very successful use as the explosive ingredient in the atomic bomb, and of the excellent prospects which it offers as the base material for the development of an atomic-energy industry. Plutonium is the only transuranium element for which methods have been developed for production in relatively large amounts—that is, kilogram amounts. The development of the chemical processes which are used in conjunction with this production have been described in a previous discussion.

From a purely scientific point of view, however, the other transuranium elements are of nearly as great an interest as plutonium. This

¹ Harrison Howe lecture delivered before the Rochester Section of the American Chemical Society, November 18, 1946. Reprinted, by permission of the American Chemical Society, from *Chemical and Engineering News*, vol. 25, February 10, 1947.

is particularly true since the whole group of heaviest elements, including uranium and those immediately below uranium as well as the four known transuranium elements and a number of as yet undiscovered elements beyond curium, are members of a transition group. This makes the chemical and physical properties of each of the elements of the whole group of comparable interest. The electron structure of these elements, in which the inner "5f shell" of electrons is being filled, with the stable structure containing seven 5f electrons occurring with tripositive curium, has been described in a previous discussion and will not be further discussed here.

Also, the radioactive properties of the new isotopes in this region contribute greatly to our knowledge of the properties of heavy radioactive isotopes, and the knowledge of the nature of the regularities of these properties contributes to the understanding of nuclear structure.

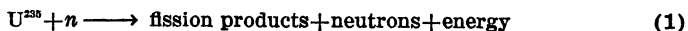
The present discussion will be concerned with the four known transuranium elements, neptunium, plutonium, americium, and curium.

NEPTUNIUM

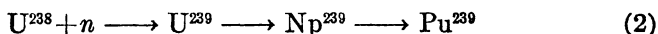
Neptunium was the first transuranium element to be discovered. Using the neutrons from the Berkeley cyclotron, E. M. McMillan and P. H. Abelson in 1940 were able to show, with the help of their chemical work, that the irradiation of uranium leads to the production of the isotope 93^{239} . This isotope, which has a half-life of 2.3 days, is the decay product of the 23-minute U^{239} formed by radiative neutron capture in U^{238} . Their experiments on the tracer scale of investigation enabled them to show that neptunium is similar in chemical properties to uranium. This was probably the most significant first evidence that the heavy elements do not have electron structures analogous to the elements immediately above them in the periodic table in which the 5d electron shell is being filled. The similarity of neptunium to uranium in chemical properties and its great dissimilarity to rhenium, immediately above it in the periodic table, was the first convincing evidence that it is the 5f electron shell which is being filled in the heavy-element region.

Another isotope of neptunium, Np^{237} , was discovered early in 1942 by bombarding uranium with fast neutrons, using the Berkeley cyclotron. This isotope is the decay product of the previously known 7-day β -particle emitting U^{237} which is formed as the result of an (n,2n) reaction on U^{238} . The isotope, Np^{237} , is of particular importance because it has a very long life, emitting α -particles with a half-life of 2.25×10^6 years, and because it is available in weighable amounts. This isotope is produced during the operation of the large uranium chain-reacting units, a very fortunate circumstance, for otherwise it is probable that the element neptunium would not be available for study in the macroscopic state.

It is of interest to give a brief description of the complex nuclear reactions which lead to the production of this isotope in the uranium-graphite chain-reacting units. As is now well known, the nuclear chain-reaction depends on the following reaction of the isotope U^{235} with neutrons:



The neutrons liberated in this fission are fast neutrons, and in the case of the natural uranium constituting such chain-reacting units these would react preferentially with the large amount of U^{238} (99.3 percent by weight) and not leave enough neutrons to react with the U^{235} to maintain the chain-reaction unless special precautions are taken. If the neutrons are reduced in energy this situation no longer applies, as the probability of the fission reaction increases markedly with decrease in neutron energy. In the uranium-graphite lattice structure, in which lumps of uranium are interspersed in a graphite matrix, the graphite slows down the fission neutrons without capturing them. The fission neutrons which originally escaped from the uranium then return from the graphite to the uranium, and after the proper proportion undergo reaction 1 again in order to perpetuate the chain, the majority of the remainder undergo the following reaction:



leading to the production of plutonium.

However, a certain proportion of the fission neutrons have a sufficiently high energy to produce the following reaction:



before they escape from the uranium into the graphite. The U^{237} formed in this manner decays to the above-mentioned Np^{237} , thus leading to the production of this isotope in the uranium in addition to the primary desired product, Pu^{239} , and the fission byproducts. In a uranium-graphite pile the Np^{237} is produced at a rate corresponding to the order of 0.1 percent of that of the primary product, Pu^{239} .

Some of the isotope Np^{237} has been recovered by suitable modification of the chemical separation process used at Hanford. As a result of this work and these special runs, several hundred milligrams of the isotope Np^{237} have been recovered and made available for the investigation of its chemical properties.

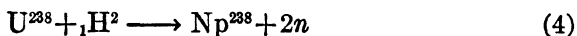
Using this material, it has been possible to make an intensive study of the chemical properties of neptunium, leading to the establishment of its oxidation states and the properties of a large number of its compounds. This work has shown that neptunium has the oxidation states VI, V, IV, and III with a general shift in stability toward the lower oxidation states as compared to uranium.

The relatively low specific α -activity of the isotope Np^{237} places the element neptunium in a class by itself in the transuranium group because it is relatively safe to handle from the health standpoint. The other transuranium elements are so highly α -radioactive that special techniques and precautions are mandatory when they are handled in ordinary, let us say milligram, amounts. However, the half-life of Np^{237} , 2.25×10^6 years, corresponds to a specific α -particle activity of some $1\frac{1}{2}$ million α -particles per minute per milligram, only about 1,000 times that of ordinary uranium. Material of this level of radioactivity can be handled without special equipment, provided reasonable care and precautions are observed.

It seems desirable to work toward the modification of the chemical separation processes used in the plutonium manufacturing plants in such a manner that the neptunium will be completely recovered in a routine manner and it seems likely that this will be done sometime in the future. When neptunium becomes available in moderate amounts, one can visualize its eventual classification as an element whose availability to chemists as a whole for study will rank along with a number of the rarer elements in the classical periodic table. In fact, it is not out of the question that neptunium may some day be used sparingly in university laboratory courses in qualitative analysis and advanced inorganic chemistry and in courses in nuclear chemistry and physics.

PLUTONIUM

Plutonium was the second transuranium element to be discovered. The first isotope to be found was Pu^{238} , an α -emitter of some 50 years' half-life, formed according to the following reactions:



The chemistry of plutonium was first investigated by the tracer technique using this isotope. These experiments showed that the chemical properties of this element are similar to those of neptunium and uranium, differing in that the lower oxidation states of plutonium are more stable.

The isotope of major importance is, of course, Pu^{239} . This isotope, which is an α -emitter with a half-life of about 24,000 years, is synthesized according to reactions 1 and 2 above, and its tremendous importance stems from its property of being fissionable with slow neutrons, together with the fact that the problem of its mass production has been solved.

The Plutonium Project of the Manhattan District was organized for the purpose of producing this isotope, the explosive ingredient for the atomic bomb. The first isolation of pure Pu^{239} and the early study of its chemistry and the design of the chemical process for its large-scale separation from uranium and fission products, which involved work on the ultramicrochemical scale with only microgram amounts of material, have been described in previous discussions.

The availability of the relatively large amounts of plutonium, as the result of the successful operation of the chain-reacting uranium piles, has made it possible to make a complete investigation of its chemical properties using methods which can be considered to be those of ordinary chemistry except for the health precautions which are necessary. This work has established that plutonium has the oxidation states VI, V, IV, and III, and that there is a shift in stability toward the III state as compared to neptunium and uranium. A large number of compounds of plutonium have been prepared and their properties determined. It may be said that the chemistry of plutonium today is as well or better understood than is that of most of the elements in the periodic system, even though its chemistry is very complex as can be judged by the multiple oxidation states.

Because of its relatively high specific α -radioactivity, amounting to about 140,000,000 α disintegrations per minute per milligram, special equipment and special precautions are necessary in the investigations of its properties. This high α -radioactivity makes it expedient to continue to use rather small amounts—that is milligram amounts—for a number of these investigations even though large amounts might be available. Even if there were no other reasons, its high α -radioactivity places plutonium outside of the class of elements which might eventually find widespread distribution among chemists for investigation of its chemical properties.

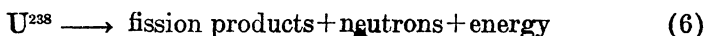
As I have indicated earlier, the question as to the existence of trans-uranium elements in nature has long been a matter for speculation and investigation. It was also indicated that it is now almost certainly known that these elements do not exist in appreciable amounts on the face of the earth. I would like to discuss this matter further because it is true that one of these elements, plutonium, has been experimentally found to exist in nature in minute amount.

The knowledge of the chemical properties of neptunium and plutonium which had become available as a result of the discovery and study of these elements made it possible to conduct very effective searches for these elements in various minerals. Early in 1942 G. T. Seaborg and M. L. Perlman in Berkeley undertook a search for these elements in pitchblende ore, the primary purpose at that time being to establish whether such a source of a fissionable transuranium isotope might serve as a practical source capable of substituting for the, at that

time, undeveloped and questionable nuclear chain-reaction for production purposes.

The ore pitchblende was chosen for this first search because it was felt that a source rich in radioactive material would offer the most hope and also because pitchblende is known to contain a large number, some 40, of different elements. About 0.5 kilogram of pitchblende ore was completely dissolved and subjected to an exhaustive chemical process designed to separate and isolate the elements neptunium and plutonium. A small quantity of α -radioactivity was found in this transuranium fraction and these investigators attributed this to the plutonium isotope, Pu^{239} . The amount of plutonium in the pitchblende corresponded to about one part in 10^{14} , an amount which could not possibly have been found had the chemical properties not been known. Thus, although the experiment proved that this could not be a practical source for the production of plutonium, it also gave good evidence that this element does exist in measurable quantities on the face of the earth.

The relatively short half-life of Pu^{239} compared to the age of the earth makes it necessary that it be continuously formed in order that it be present on the earth in any detectable amount. There is a mechanism for its continuous formation which can both qualitatively and quantitatively account for its presence in pitchblende. Uranium undergoes spontaneous fission according to the following reaction:



and the rate corresponds to a "half-life" for this process of some 10^{16} years. If all the neutrons from this process are reabsorbed by U^{238} to form Pu^{239} according to reaction 2 above, the amount of Pu^{239} in the pitchblende in equilibrium with its parent U^{238} would be (assuming two neutrons per spontaneous fission) $2 \times 24,000 / 10^{16} =$ approximately 500 parts in 10^{14} . This corresponds to some 100 or 200 parts of Pu^{239} per 10^{14} parts of pitchblende. Thus only about 1 percent of the spontaneous fission neutrons need be absorbed by U^{238} , the remainder either escaping or being reabsorbed by the many neutron-absorbing impurities in the pitchblende, in order to account for the Pu^{239} present.

There are, of course, other sources of neutrons which may be of comparable importance in the formation of this Pu^{239} . For example, uranium, and especially its decay products, emits α -particles which can give rise to neutrons according to the well-known (α , n) reaction as a result of their reaction with light nuclei—for example, lithium, boron, beryllium, fluorine, oxygen, etc.—in the pitchblende.

A further search for the presence of transuranium elements in nature was made during the summer of 1942. Another radioactive ore—namely, carnotite—was chosen this time, the investigation being carried out by C. S. Garner, N. A. Bonner, and G. T. Seaborg. As in the

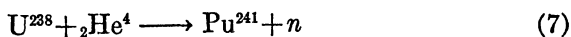
case of the pitchblende a transuranium fraction which would contain neptunium and plutonium was carefully isolated from the completely dissolved carnotite ore, about 5 kilograms being used in this case. Again an alpha-radioactivity was found, the concentration of the corresponding Pu^{239} being comparable to that found in the pitchblende.

It was originally intended to extend the search for transuranium elements to a number of other ores, but the exigencies of the investigations in connection with the Plutonium Project made it impossible to carry out this program. Such a program did not seem justified in view of the small amounts which had been found in the pitchblende and carnotite. The results of the investigation tempt one toward the conclusion that transuranium elements do not exist in practical amounts on the face of the earth. There will, of course, be some neptunium, in the form of the isotope Np^{237} , present in pitchblende, carnotite and other uranium-bearing ores formed as the result of reaction 3 above, but it seems very likely that the concentration of this is even smaller than the concentration of the plutonium. The amounts of americium and curium on the basis of present indications would appear to be even smaller. However, there is just an outside possibility that there might exist some transuranium isotope or isotopes, perhaps, whose radiation characteristics have not yet been characterized, formed by a mechanism as yet not conceived. Thus, although it appears that transuranium elements do not exist on the earth in any ores in concentrations larger than some one part per 10^{14} , it might be a little premature to make this statement too definite and further searches for such elements might be worth while.

AMERICIUM

Americium, the element with atomic number 95, was the fourth transuranium element to be discovered, its first identification taking place late in 1944 and early in 1945. The first isotope of this element was identified in the experiments of G. T. Seaborg, R. A. James, and L. O. Morgan at the Metallurgical Laboratory of the University of Chicago.

The bombardment of U^{238} with very high-energy (40 to 44 Mev.) helium ions in the cyclotron leads to the formation of the isotope of americium with mass 241—that is, Am^{241} . The Am^{241} is the daughter of a relatively long-lived β -emitting Pu^{241} which is formed in the primary reaction of U^{238} and helium ions. The reactions therefore are as follows:



The isotope Am^{241} emits α -particles with a half-life of 500 years.

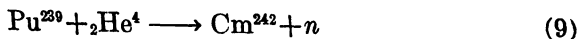
The availability of this isotope of americium made it possible to study the chemical properties of this element using the tracer technique. Deductions from this work led to the conclusion that this element probably exists in aqueous solution in only the one oxidation state, the III state. This is in line with the tendency toward the stabilization of the lower oxidation states in going to the heavier elements in this region.

It has recently been possible to isolate americium in the form of a pure compound of this element. B. B. Cunningham, working at the Metallurgical Laboratory, has succeeded in isolating this element and in studying its chemical properties using a weighable amount on the ultramicrochemical scale. This is a remarkable achievement in that the amounts available here were even smaller than those in the case of neptunium and plutonium. This, then, is the third synthetic element which has been isolated in pure form. The work of Cunningham and L. B. Werner with pure americium in aqueous solution has confirmed the tracer work by showing that the III oxidation state is very stable in solution and is the predominant and most important state.

Americium, with its 500-year half-life, has a higher specific α -activity than even Pu^{239} . Its specific α -activity amounts to some 7 billion α disintegrations per minute per milligram. Thus even if this element should become available in ordinary amounts, let us say, milligram amounts, it will always be necessary to conduct its investigation with special precautions and using the special techniques for handling highly α -active material. The investigation of the chemical properties of americium will demand investigators who are well trained with handling highly α -active materials.

CURIUM

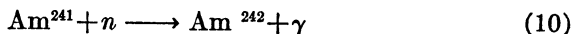
Curium was the third transuranium element to be discovered. The first isotope of this element was the isotope, Cm^{242} , which was identified in 1944 by G. T. Seaborg, R. A. James, and A. Ghiorso at the Metallurgical Laboratory as the result of its production in the Berkeley 60-inch cyclotron by the following reaction:



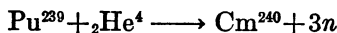
The isotope, Cm^{242} , is an α -particle emitter with a half-life of about 5 months.

The availability of this isotope of curium made it possible to study the chemical properties of this element by use of the tracer technique. Extensive investigations have led to the conclusion that curium probably exists exclusively in the III oxidation state in aqueous solution. It is carried quantitatively by the rare earth fluorides in precipitation reactions and can be separated from them only with difficulty.

The isotope Cm^{242} is also formed as the result of the strong neutron irradiation of Am^{241} . The Am^{241} absorbs neutrons to form a short-lived (18-hour half-life) β -emitter, Am^{242} , which in turn decays to the Cm^{242} . These nuclear reactions may be summarized as follows:



Another isotope of curium is also known. The bombardment of Pu^{239} with 44-Mev. helium ions leads to the production of the 1-month α -emitting Cm^{240} by the reaction:



The relative yield of Cm^{240} compared to the yield of Cm^{242} from reaction 9 above increases with increasing energy of the helium ions.

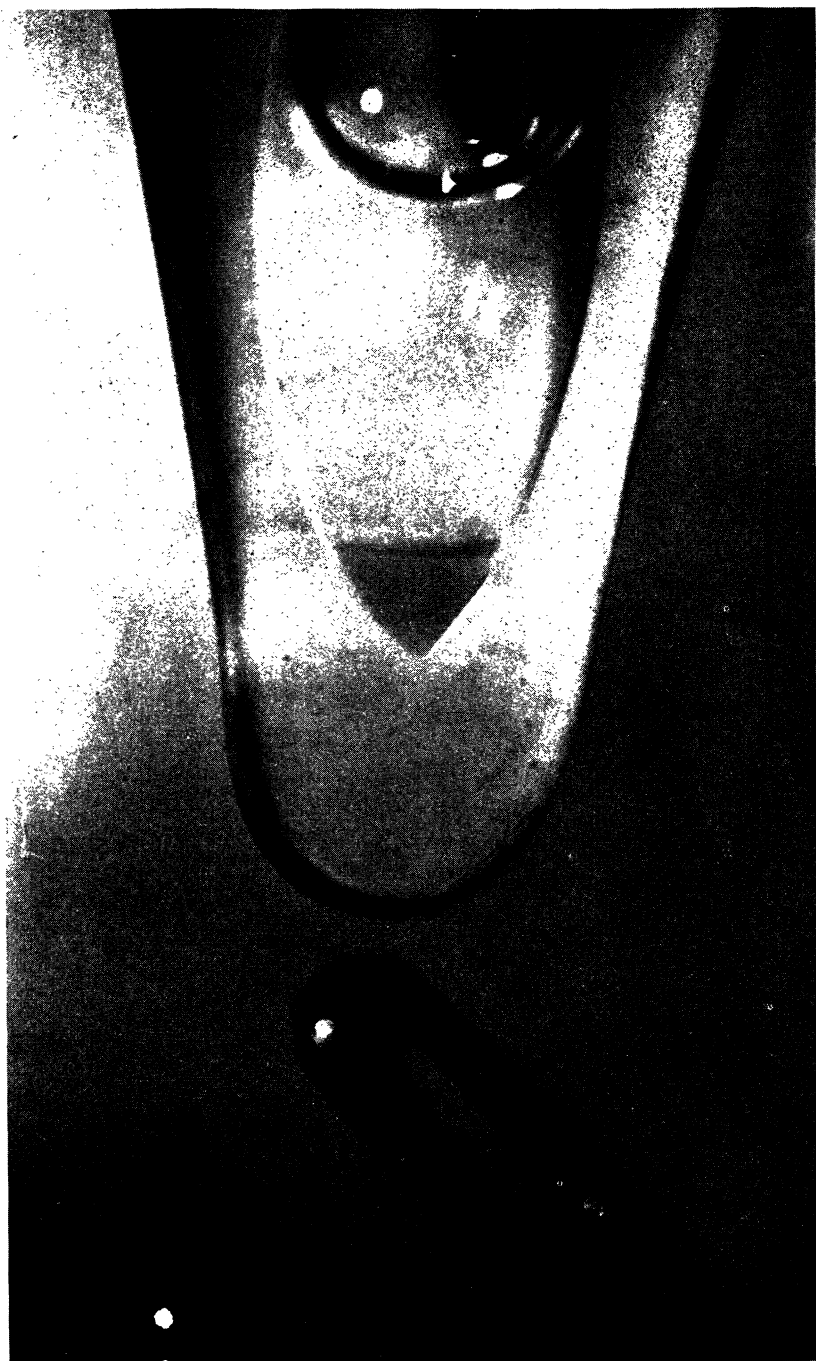
The element curium has not yet been isolated in the pure state and therefore this is the only one of the four known transuranium elements for which this has not been done.² It is, of course, of interest to inquire whether it will be possible to do this in the future. Apparently this will be difficult with the present isotopes, Cm^{242} or Cm^{240} , since these have rather short half-lives—namely, approximately 5 months and 1 month, respectively. As has been the case for the other three transuranium elements the first isolation of curium in the pure state will probably take place as the result of work on the ultramicrochemical scale with microgram or less amounts of material.

The isotope Cm^{242} with its 5-month half-life has a specific α -activity corresponding to about 10^{13} α disintegrations per minute per milligram. This will mean that even 1 microgram will correspond to some 10^{11} disintegrations per minute. A specific α -radioactivity of this magnitude gives rise to problems due to the aggregate recoil of submicrogram particles as a result of the tremendous rate of α -emission. Nevertheless, it seems entirely possible and even likely that curium, probably in the form of the longer-lived isotope Cm^{242} , will be isolated in the pure state as soon as the problem of its production in microgram amounts is solved. Once this pure element is available in microgram amounts it will be possible to study its chemistry by means of investigations on the ultramicrochemical scale, although each measurement in this case will be most difficult and laborious. Among the difficulties here will be the rapid decomposition of the water in the solution, the formation of hydrogen peroxide in the solution, heating of the solution, and other effects. However, as in the cases of the other

² Curium was isolated in pure form in the fall of 1947 by L. B. Werner and J. Perlman at the University of California.

three transuranium elements, where it was possible to graduate from tracer scale investigations to the more certain investigations with the pure elements, it does not seem too optimistic to hope that this will soon also be true for curium.

It is, of course, not improbable that it will eventually be possible to prepare isotopes of curium of longer half-life. It is, in fact, even probable that isotopes such as Cm^{243} , Cm^{244} , Cm^{245} , or Cm^{246} may have longer half-lives and that these isotopes may eventually become available for investigation.



PRECIPITATE OF AMERICIUM HYDROXIDE IN CAPILLARY TUBE
Eye of needle shows degree of magnification.

THE USE OF ISOTOPES AS TRACERS ¹

By A. H. W. ATEN, Jr.

and

F. A. HEYN

[With 1 plate]

INTRODUCTION

When the periodic system of chemical elements was set up in the course of the previous century, it was thought that each element consisted of only one definite kind of atom. Later this was found to be incorrect: an element may consist of different kinds of atoms which have practically identical chemical properties—the criterion for denoting the atoms by the name of the respective element—but differ in atomic weight by one or more units. Such isotopic atoms, so called because they have to be given the same position in the periodic system, may be stable or unstable. In the latter case they undergo a gradual change, accompanied by a radiation, into another kind of atom; they are then radioactive.

Almost all the kinds of atoms occurring in nature are stable. There are only a few unstable ones, namely the well-known substances with natural radioactivity, such as radium, thorium, uranium, etc. In addition to these, however, it is nowadays possible to turn each element into one or more new isotopes which do not occur in nature, all of which are unstable (artificial radioactive substances).

A single example will serve to illustrate the above. The element calcium occurring in nature consists of six stable isotopic kinds of atoms, namely, for 96.96 percent Ca^{40} , i. e., calcium atoms with an atomic weight of 40 (in round numbers), and further 0.64 percent Ca^{42} , 0.15 percent Ca^{43} , 2.06 percent Ca^{44} , 0.0033 percent Ca^{46} and 0.19 percent Ca^{48} . Furthermore, up to the beginning of the year 1944 it had been found possible to make artificially six more radioactive calcium isotopes with atomic weights 39, 39, 41, 45, 49, 49. The various unstable isotopes can further be distinguished from each other by the character of their radioactivity. In the case of a radioactive atom a

¹ Reprinted by permission from Phillips Technical Review, vol. 8, No. 10, October 1946.

certain percentage of the atomic nuclei present is transformed per second into another sort by spontaneous disintegration, each disintegrating nucleus emitting, according to its sort, a negative or positive electron or an α -particle (helium-nucleus). This is often accompanied by an electromagnetic radiation (γ -radiation). The intensity of the total radiation of a radioactive preparation at any moment can easily be measured. As the number of nondisintegrated atomic nuclei is continually decreasing, while the chance of disintegration remains constant for each atom and thus also the percentage of nuclei disintegrating per second, the radioactivity observed decreases with time. The velocity of this decrease usually expressed by the "half-value time," i. e., the time in which the intensity of the radiation falls to one-half, is characteristic for each isotope. The above-mentioned six radioactive calcium isotopes have half-value times of 4.5 minutes, 1.06 seconds, 8.5 days, 180 days, 2.5 hours, and 30 minutes respectively.

The existence of the isotopes is not merely of theoretical interest. In the last 10 to 20 years isotopes have become an extremely useful practical aid for all kinds of scientific and technical investigations. This use of isotopes is based for a large part on the fact that an isolated isotope of an element takes part in chemical and physical processes in exactly the same way as the familiar mixture of isotopes of that element which occurs in nature, while the isotope in question can always be recognized by the investigator and can be traced even in a chemically identical environment, thanks to its radioactivity or difference in atomic weight. The isotope thus functions as a tracer, capable of furnishing information about the process taking place, which would be much more difficult or even quite impossible to obtain in any other way.

We shall explain this in more detail, but for better orientation of the reader we shall first discuss four examples out of the large number of investigations which have already been carried out with isotopes as tracers.

WHAT CAN BE DONE WITH (RADIOACTIVE) ISOTOPIC TRACERS

First example.—In the production of steel, among other substances the phosphorus, which is present in quite considerable quantities in the crude iron, has to be rendered harmless by adding a slag-forming substance or by lining the crucible with a material that reacts with phosphorus. A continuous check has then to be kept of the amount of phosphorus still present in the molten metal. This can, of course, be done by chemical analysis of samples, but results are obtained much more quickly and easily when a small amount of radioactive phosphorus is added to the melt at the beginning of the process. This is rapidly distributed uniformly throughout the melt, so that the ratio between the natural phosphorus present and the radioactive phos-

phorus added is the same everywhere. If phosphorus disappears from the melt into the slag floating on the surface or into the lining of the crucible this takes place to an equal degree with the natural and with the radioactive element. The decrease in the percentage of phosphorus in the melt can thus be determined merely by ascertaining the decrease in the radioactive phosphorus. This is extremely simple, since it is only necessary to measure the radioactivity of a sample of the melt, which can be done very easily with an electrometer or an electron counter.²

Second example.—In many factories the workers come into contact with mercury, and it is known how harmful the regular inhalation of mercury vapor can be; in course of time a concentration of more than 10^{-4} gram of mercury per m^3 of air already becomes injurious to health. It is a difficult problem to detect the presence of mercury in such minute proportions, because chemical analyses are unavailing in such cases. In a certain case which occurred in the manufacture of tubular luminescent lamps in an American factory, where the lamps were filled with mercury vapor at a low pressure, a glass side-tube containing a small drop of mercury had to be "blown" onto the lamp, and inevitably the glass blower inhaled a very small quantity of mercury vapor into his lungs. In order to determine how much was inhaled a number of tests were carried out with a volume of 2 liters of air that had been in contact with the drops of mercury under exactly the same conditions as in the manufacturing process, this being drawn off by suction and passed over a metal plate kept at the temperature of liquid air. Practically all the mercury in the air condensed on the plate.

The mercury used for the experiments contained a known, small percentage of a radioactive mercury isotope. The radioactivity of the plate, which was quite simple to measure after the experiment, gave an indication of the amount of mercury contained in the air which had passed over the plate. In this way a concentration of 5×10^{-6} g/m^3 could be detected. Average mercury concentrations were found of about 10^{-5} and in one case about 4×10^{-5} g/m^3 , from which it was concluded that in the manufacturing process in question the glass blower ran no danger of poisoning.³

Third example.—When a piece of metal is fused with a radioactive lead isotope in an atmosphere of hydrogen and then allowed to crystallize again, there are two possibilities. In some metals, such as thallium and magnesium, lead is soluble to a considerable percentage, the lead atoms being uniformly distributed in the grains and the poly-

² An electron counter was described, e. g., by A. Bouwers and F. A. Heyn, in *Philips Techn. Rev.*, vol. 6, p. 75, 1941. In the measurements allowance must of course be made for the natural decline in radioactivity with time. We shall return to such practical details on a later occasion.

³ J. W. Irvine and C. Goodman, *Journ. Appl. Phys.*, vol. 14, p. 496, 1943.

crystalline metal obtained. In other metals, on the other hand, such as bismuth, tin, antimony, silver, gold, copper, and nickel, in which lead is practically insoluble, the radioactive lead is situated on the boundaries of the grains. When a microscopic preparation of the metal is made and laid on a photographic plate for several hours after development, the plate will be found to be blackened at those places where it lay against radioactive particles, thus where lead has been deposited. By means of such an "autoradiogram," of which plate 1, figure 1 is an illustration, it is possible in the first place to ascertain whether and to what degree the added lead is soluble in the metal; if the lead is entirely dissolved the entire surface of the photographic plate is uniformly blackened; if the lead does not dissolve, or only partially, the radiogram shows up very nicely also the boundaries of the grains (pl. 1, fig. 1). Thus the isotopic method can also in this case furnish valuable information about the changes taking place in the structure of the metal upon recrystallization and in rolling.⁴

Fourth example.—Friction between two metal surfaces is due partly to adhesion, the result being that when the surfaces slide over each other extremely small particles of metal are torn out of one and taken up in the other. This exchange of metal may take place to such an extent that two surfaces become, as it were, welded together (the familiar seizing). The quantity of material thus transferred from one metal to the other is a measure of the contribution of this effect to the total force of friction. In general it is a question of very small amounts which chemically can hardly be detected at all. An investigation has now been carried out with the help of a radioactive tracer.⁵ One metal surface was "activated," i. e., it consisted for a small part of atoms of a radioactive isotope of the metal. After this surface had been made to slide over the second, nonactivated metal surface, the latter also showed a certain amount of radioactivity. Amounts of 10^{-10} gram of transferred metal were detected in this way, and, what is more, by means of a radiogram, as described in the preceding example, also the distribution of the transferred material on the surface could be studied. From the radiogram shown in plate 1, figure 2, *a*, it may be concluded, for example, that in this experiment the sliding of the two metal surfaces over each other was not continuous but took place in small jerks. By this method the influence of all kinds of factors, such as the pressure, the hardness of the surface, etc., on the transfer of material can be studied, as also the effect of a lubricant. (See pl. 1, fig. 2, *b*.)

⁴ G. Tammann and G. Bandel, *Zeitschr. Metallk.*, vol. 25, pp. 153 and 207, 1933.

⁵ B. W. Sakmann, J. T. Burwell, and J. W. Irvine, *Journ. Appl. Phys.*, vol. 15, p. 495, 1944; J. N. Gregory, *Nature (London)*, vol. 157, p. 444, Apr. 6, 1946.

WHY THE TRACER METHOD IS SO IMPORTANT

From these few examples we can already deduce the most important aspects which have lent such great significance to the tracer method.

We first call attention to the last example discussed. The transfer of material can also be measured when the two surfaces sliding over each other contain the same metals or even when they are exactly identical. It must be realized that this would not be possible by any other known method, since the transfer takes place in both directions: there is an exchange of identical particles. It would not be possible by any chemical or physical method to ascertain the origin of the metal present on one of the surfaces after the experiment, whereas the radioactive isotope immediately gives the answer.

Processes in which there is an exchange of identical particles are very common in nature, not only in chemistry and metallurgy, but especially in the physiology of plants and animals. The tracer method, which offers the only method of approach, has been used on a large scale for the investigation of such processes, and the publications in that field are innumerable. In a survey of such investigations for the year 1940⁶ in physiology alone more than 300 publications are cited. But also in the field of technology, for routine tests, and likewise in agriculture and chemistry, the method is being more and more widely applied.⁷

Although the last example discussed illustrates the possibility of studying the exchange of identical particles with the help of an isotope, the employment of the tracer method in that case is not motivated only by the possibility mentioned. When two different metals slide over each other the transfer of material could in principle be studied also by other methods. The fact that a radioactive tracer is, nevertheless, used, is due to the fact that a much greater sensitivity can be attained with the radioactivity measurements, i. e., much smaller amounts of a substance can be detected than with other methods so far available. The same applies to the case of the determination of mercury. In the determination of phosphorus, which was discussed as the first example, the indicator method is not necessary in principle either, but it was applied there because of the greater ease with which the quantity of phosphorus could be determined, compared with a chemical or other analysis. Finally, an important point in the employment of a radioactive isotope is that it can be localized so easily when mixed with a different or a chemically identical substance, while also its distribution can be determined. (See the radiograms of pl. 1, figs. 1 and 2.)

⁶ J. R. Loofbrourow, *Rev. Mod. Phys.*, vol. 12, p. 267, 1940.

⁷ See, for example, the survey of chemical applications by G. Seaborg, *Chem. Rev.*, vol. 27, p. 199, 1940, where more than 500 publications are mentioned, most of them different from those in the article by Loofbrourow.

Where radioactive isotopes are applied for the sake of the advantages of greater sensitivity and easier working, while in principle other methods would also provide an answer to the questions raised, one might speak of "untrue" applications of the indicator method. In such cases the nature of the isotope is sometimes a matter of indifference; in order to obtain a radiogram of the grain boundaries in a polycrystalline material it would also be possible to use a radioactive isotope of some metal other than lead, provided it does not dissolve in the base metal. In the "true" applications of the tracer method it is quite different, for there it is essential that an isotope can be detected in identical surroundings.

In this connection attention should be called to the fact that the tracer method can also be applied with nonradioactive isotopes. The atoms of such isotopes are recognizable (labeled) by their different atomic weight and the properties connected therewith, such as specific weight, velocity of diffusion, heat conductivity, etc. The most important atoms to be considered are "heavy hydrogen" (deuterium) of atomic weight 2 (approximate), the oxygen isotope of atomic weight 18, and the nitrogen isotope of atomic weight 15. With such stable isotopes the measurement of the radioactivity of mixtures of isotopes is replaced by measurements of density or the like.

These measurements are generally much less easy than the measurement of radioactivity and also not so sensitive by far. With stable isotopes there is, therefore, no question of "untrue" applications of the tracer method. The reason for using these is solely the possibility of studying processes of exchange, where no suitable radioactive isotopes can be found.

Owing to the very large number of applications of the indicator method (true and untrue) it has become impossible, as well as purposeless, to give a survey of these applications, even if one confined oneself to a definite field. We shall not, therefore, attempt to do so, but in the following we shall say something about the origin of the method and follow this up with a number of suitably chosen examples, with the intention of showing the possibilities of the method from different angles. In a subsequent article we shall go more deeply into the practical performance of investigations with radioactive and also with stable isotopes. As to this practical performance we can only point out here that it is not necessary to prepare the radioactive (or stable) isotopes oneself, for they can be obtained from certain suitably equipped laboratories. In Europe the Philips Laboratory in Eindhoven, among others, has already supplied suitable radioactive substances for a number of applications.

ORIGIN OF THE METHOD

The tracer method was initiated by Hevesy, who first discovered the possibility of studying processes of exchange by that means and immediately put his ideas into practice (in 1915). He used the method, for instance, to test the theory of Arrhenius about the dissociation of electrolytes. In essence his experiment was as follows. From a certain amount of normal lead a lead salt is prepared, for instance lead chloride, and from a corresponding amount of the radioactive lead isotope, which is formed as a disintegration product of radium, another salt, for instance lead nitrate, is prepared. When the two salts are dissolved in water, the solutions mixed, and then the two salts extracted separately from the mixture, the two lead compounds are found to have become equally radioactive.

The lead atoms from the two salts must, therefore, have been completely mixed in the solution. This result agrees entirely with the hypothesis that the lead compounds are dissociated in the solution, i. e., that lead occurs therein in the form of free ions.

We have just said that one salt was prepared from normal lead and the other from the radioactive lead isotope. Consequently, in order to carry out the experiment in this way a sample of the pure radioactive lead isotope would have to be available. Actually, however, this is not necessary. It is sufficient if one sample of lead contains only a small amount of the radioactive isotope. Hevesy recognized this from the very beginning, as may be seen from the curious story of the way in which he came to use the isotopes in this way. He had tried in vain to separate radium D from a quantity of lead containing a small amount of that substance. Since radium D is an isotope of lead (the radioactive isotope mentioned in the radium series; its name dates from the time when there was no clear idea of the situation), it cannot, as we now know, be separated by ordinary chemical means. It was just this failure that gave Hevesy the idea that he could always distinguish the lead of this sample "contaminated" with radium D from a sample of ordinary lead: in all mixtures with ordinary lead every fraction of the "contaminated" (radioactive) lead sample takes an equal fraction of the original radioactivity with it and can thus be determined quantitatively by measurement of the radioactivity.

The "contaminated" lead is thus, as it were, indicated or labeled by the radioactive isotope itself, and provided it is a homogeneous mixture the whole sample can serve as a quantity of labeled atoms. This is in fact obvious when it is borne in mind that the radioactivity of an element only means that per unit of time a certain percentage of the atoms present in a sample disintegrates spontaneously. If the sample also contains a number of isotopic atoms which are stable and thus will never disintegrate, the only result, in the first instance, is that the percentage of disintegrating atoms per unit of time, is smaller, thus the radioactivity is "diluted." In fact, also in the first examples discussed there were

certain dilutions of radioactive phosphorus and mercury, and this is usually the case with artificial radioactive substances where the degree of "concentration" of the radioactivity depends upon the preparation of the substance.

Hevesy's applications of radioactive substances were not confined to exchange experiments. He realized also the significance of radioactivity measurements as a substitute for chemical analyses, owing to the great ease and sensitivity of the method as illustrated by our first examples, and he thus also made use of "untrue" applications of indicators. Once, when he had reason to suspect the cleanliness of his landlady, he smeared a bit of "dirt" with a radioactive substance on his dinner plate and checked daily whether the plate had been properly washed simply by measuring the radioactivity which (literally) still clung to it. He was indeed able to detect radioactivity of the plate for many days. Whether or not this was to be ascribed to the carelessness of the landlady or to the extreme sensitivity of the method, history fails to relate.

DENOMINATION OF THE METHOD

Hevesy called a radioactive isotope used for the experiments described, an indicator, and thus following his example one often speaks of the indicator method. In recent years in English-speaking countries the terms "tracer method" and "tracer atoms" have become more usual: The radioactive isotopes are used, as it were, for discovering and following a trace. "Labeled" and "tagged" atoms are also often spoken of. The terms speak for themselves. Finally, to complete the list, we may mention the denoting of these atoms as "spies," as proposed by Evans.* This name is meant to indicate that each atom of a radioactive isotope can move about unrecognized in a "crowd" of even similar atoms until at a certain moment it "betrays" its presence and whereabouts by its disintegration. The concentration of "spies" in the experiments usually lies between 1 to 10^{10} and 1 to 10^{15} normal individuals. Translated into terms of human society, this would be equivalent to one spy among a population at least five times as large as that of the whole earth.

FURTHER EXAMPLES OF THE APPLICATION OF TRACERS

The examples which will be discussed in the following in unrelated order, will give the reader an idea of the multifarious nature of the applications of indicators. In order to reduce them to some kind of systematic order we have sorted out the examples into three groups according to the character of the problem. In the first group the problem is only where something is situated (localization), in the second

* R. D. Evans, *Applied Nuclear Physics*, Journ. Appl. Phys., vol. 12, p. 260, 1941.

group how much of a substance there is, remains behind, or takes part in a process (quantitative problems) ; in the third group it is particularly a question of exchange processes. It must be said, however, that often the boundaries between the groups cannot be sharply drawn. In localization problems one is obviously always concerned with "untrue" indicator applications, as is also usually the case in the second group (quantitative problems), while the last group contains only "true" cases.

Localization.—A very old example is the tracing of samples of radium that have been lost in hospitals through carelessness or theft; the places where the sample might possibly be, for instance the refuse heap, are gone over with an electron counter. A more modern case is the tracing of stoppages in an oil pipe line. In the periodical cleaning of the walls of the pipe a screw-shaped scraper is placed in the line and pushed along by the pressure of the oil itself. If the scraper gets jammed somewhere, it has to be located as quickly as possible, in order to open the line at that point and remove the accumulated deposit. With the help of a radioactive indicator this localization is astonishingly simple. A scraper is used that contains a little radioactive material emitting γ -radiation, which easily penetrates through the walls of the pipe and can be detected with a somewhat modified "electron counter." One rides along the line with this "counting" apparatus until the radioactivity betrays the position where the scraper has stopped.

There is another similar application in the petroleum industry, for determining the setting depth of the cement that is pumped in behind the casing of an oil well. A radioactive mineral, carnotite, is mixed with the cement and when a counting instrument is lowered into the drill hole it indicates a strong radiation at the level of the cement.

Extremely fine cracks in metal surfaces can be detected and localized by applying a greasy paste containing a radioactive substance to the surface of the metal under high pressure. Upon the surface being cleaned, the radioactive paste is left in the cracks, and by making an autoradiogram of the surface the cracks can then easily be seen.

Quantitative problems.—In order to determine the efficiency of a fog, smoke, or dust filter, it is necessary to measure the very small quantities of fog-forming or other substances retained by the filter. As fog-forming substance, tricresyl phosphate, containing radioactive phosphorus is used. When this is passed successively through several filters, their efficiency can be judged by comparing the intensity of their radioactivity.

Radioactive isotopes are sometimes an excellent means of measuring very small solubilities or very low vapor pressures. The vapor pressure of thorium acetyl acetate, for example, has been determined

by preparing a sample of the compound with a strongly radioactive thorium isotope, saturating a given volume of nitrogen with the vapor of the compound and passing the gas through acidified alcohol, in which the compound is absorbed. The thorium concentration can then be calculated from the radioactivity of the liquid and from that the amount of vapor in the given volume of nitrogen.

In general it may be said that radioactive isotopes render valuable service in microchemistry, i. e., the chemical investigation of extremely small quantities of a substance, as for instance in adsorption phenomena, in very dilute solutions, etc. Another interesting fact is that radioactivity has made possible the investigation of the chemical properties of the elements "43" and "85" and of several "transuraniums," elements which could not be found in nature but from which radioactive isotopes could be prepared artificially in imponderably small quantities.

Important perspectives are opened by the application of radioactive indicators in chemical analysis, so often constituting daily routine work in technology. One example out of many is the following. It is desired to determine the bromine content in a mixture of a bromide and a chloride. A complete separation of the two compounds is very difficult and takes up a great deal of time. If, however, a little radioactive bromine (in the form of the compound in question) is added to the mixture, only a partial separation of the bromine is sufficient. Due to the homogeneous mixing it is known that the ratio between the bromine separated and the total amount of bromine is equal to the ratio between the radioactivity separated out and the original radioactivity. Since the latter ratio is easily determined, it is possible to calculate the desired total content of bromine directly from the amount of bromine separated out.

An application in biology somewhat resembling the above is the determination of the total amount of blood in an animal. After a certain amount of blood has been taken death inevitably sets in and it is then impossible to draw off the rest of the blood. If, however, a solution of some substance or other containing a known quantity of radioactive atoms is injected into the test animal intravenously and given time to distribute itself homogeneously throughout the whole circulatory system, a small sample of the blood suffices, for the total amount of blood can then be calculated from the percentage of injected radioactive atoms recovered in the sample. (Of course, no appreciable part of the injected substance must have been transferred from the blood to other parts of the body.)

The fact that it is practically unnecessary to interfere with the normal life of the test animal is of importance for many investigations, especially those of a pharmacodynamic nature. We may men-

tion here an investigation into the rate of absorption of insulin which is injected periodically under the skin of sufferers from diabetes. It is often desirable to restrict the number of injections and it is therefore favorable if the insulin is retained for a relatively long time near the point of injection, or stored there as it were, and only slowly taken up in the circulation. By building a radioactive atom (radioactive iodine) into the molecule of three kinds of insulin, viz., "ordinary" insulin, globine insulin, and protamine-zinc insulin, and measuring from time to time the decrease of radioactivity at the point of injection, it has been possible to determine that the rate of absorption of the three kinds of insulin in the body decreases in the order given above.

Exchange processes.—Although also in chemistry and technology numerous processes play a part where an exchange of identical particles occurs—we mention only autodiffusion, e. g., the diffusion of lead atoms in lead—physiology is the most prominent field for such exchanges. One of the most striking examples is the continuous exchange of the building materials of the body. This has been studied in detail with phosphorus in the form of various compounds, with the help of radioactive phosphorus, which lends itself so well for such experiments. Particularly Hevesy has done a great deal of these investigations. It has been established that phosphorus does not remain permanently bound in any constituent of the body. The exchange takes place most rapidly between the blood and various organs: of the phosphate ions present in the blood at a given moment after 2 hours, only 2 percent are still present, the rest having been exchanged. In the liver and kidneys, too, there is a rapid renewal, but also in the bones and even in the brain the phosphorus is in course of time renewed, though at a much slower rate. The parts of the body that take least part in the continual exchange are the teeth: after 250 days only 1 percent of the phosphorus in the dental enamel is renewed.

In a certain case it is not so much a matter of exchange as one of selective assimilation of substances by certain constituents of the body, namely where the exchange leads, as it were, to a credit balance for that part of the body. A striking example is the assimilation of iodine by the thyroid gland. With the help of a radioactive iodine isotope it has been determined that, out of an extra amount of iodine administered in the food, after 1 or 2 days a healthy person has stored up in the thyroid gland about 3 percent, whereas a sufferer from goitre stores up 30 percent or more. (See fig. 1.) In certain cases of cancer of the thyroid gland the radioactive iodine was found to be accumulated not in the cancer tissue but in the healthy tissue. (Thus we again arrive at the problems referred to under "localization.") Somewhat similar phenomena are found in the case of the assimilation of radioactive strontium in the blood and in the bones. It has been possible not only

to determine how this process is retarded, for instance, by rickets and then promoted by the administration of vitamin D, and how it is even led in the opposite direction by Basedow's disease, but it has also been possible to study the finer distribution of the strontium assimilated: the strontium was found to accumulate in the hard bone tissue, and in the case of bone cancer it showed a preference for the cancer tissue and possible metastases thereof. Though straying from our subject, it should be pointed out that this last case may be of value to the doctor not only diagnostically but also therapeutically. Given a sufficiently

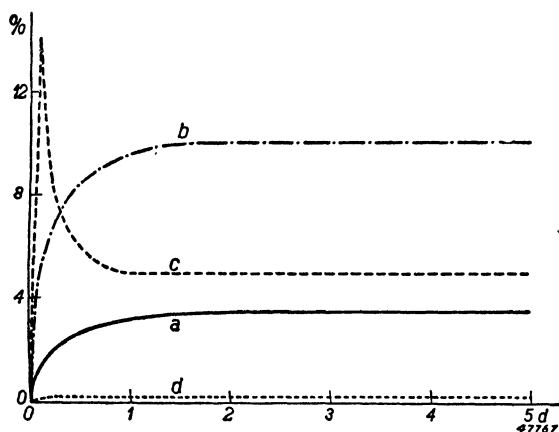


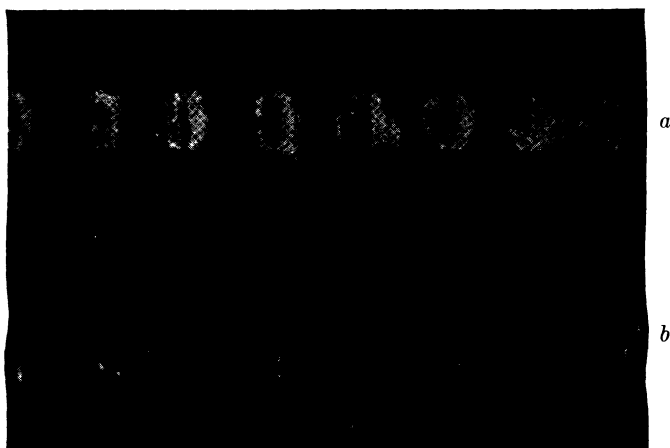
FIGURE 1.—The assimilation of iodine in the thyroid gland. Along the abscissa is the number of days which has elapsed after the administration of a known extra amount of iodine in food; along the ordinate the percentage of this amount found in the thyroid gland as measured by means of radioactive iodine: *a*, for healthy persons; *b*, with benign goitre; *c*, with Basedow's disease; *d*, upon defective functioning of the thyroid gland (myxoedema). (From J. G. Hamilton, *Application of radioactive tracers to biology and medicine*, Journ. Appl. Phys., vol. 12, pp. 440-460, 1941.)

high concentration the radiation of a radioactive kind of atom has a destructive effect on the cancer tissue. If the radiating substance is selectively attracted by the cancer cells, as strontium by bone cancer, this may eventually serve as the basis of a very effective therapeutic treatment. On the other hand, for physiological applications of radioactive isotopes as indicators it is a general rule that the destructive effect of the radiation must be avoided by keeping the concentrations of the radioactive isotopes sufficiently small.

We shall leave it at these examples. They are sufficient to give the reader an impression of what can be achieved with the tracer method in research work and routine investigation, a method for which uses are to be found in ever-increasing numbers and in even wider fields.



1. Radiogram of tin with a radioactive lead isotope (thorium B) deposited at the grain boundaries of the polycrystalline metal. Magnified about six times. (From G. Tammann and G. Bandel, Zeitschr. Metallk., vol. 25, p. 154, 1933.)



2. Radiograms of a metal surface after it has been rubbed with a piece of metal containing a radioactive component. The radioactivity of the surface shows there had been a transfer of material. This explains to a large extent the friction set up when one surface slides over another. The illustration relates to the friction of lead on steel: *a*, with no lubricant; *b*, with lubricant. Magnified about six times. (From J. N. Gregory, Nature (London), vol. 157, p. 444, 1946.)

SILICONES—A NEW CONTINENT IN THE WORLD OF CHEMISTRY¹

By S. L. BASS

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[With 3 plates]

When Columbus started out, the coast of Europe was well known and the coast of China had been explored. He assumed, therefore, that by sailing west from Europe he would reach the coast of China. No one knew then that a great continent lay between Europe and Asia.

The same condition was, until quite recently, true in the chemical world. Men had known about inorganic materials such as ceramics, glass, and metals for centuries. They had known of organic materials based principally upon carbon and its compounds for generations and had developed thousands of synthetic organic materials in the more recent past. But no one knew that between these two fields lay a new chemical continent of semi-inorganic materials known today as silicones. Organic chemists started to explore the simple organo-silicon compounds some 50 years ago. It was not until the early 1930's however, when chemists at the Corning Glass Works started to investigate the organo-silicon oxide high polymers that the importance of this new chemical continent began to appear.

Like glasses and the mineral silicates, of which fibrous glass, mica, and asbestos are familiar forms of heat-resistant insulating materials, the silicones also are derived from silica. Chemically, the silicones, like glass and the mineral silicates, are built upon a heat-stable skeletal structure of silicon atoms joined to each other through oxygen atoms. In the silicones, however, each silicon atom has attached to it one or more organic groups.

THE SILICONE MOLECULE

Sand is the source of silicones, just as it is of glass. However, instead of its being combined with inorganic oxides from lime and soda, it is altered rather radically by being put through a series of chemi-

¹ Reprinted by permission from *Electrical Engineering*, vol. 66, No. 4, April 1947.

cal processes. A grain of sand is, in effect, a complex molecule of silica. Each silicon atom is linked to four oxygen atoms which in turn link it with other silicon atoms. In making silicones, part of those oxygen atoms are replaced by organic hydrocarbon groups derived from coal or oil.

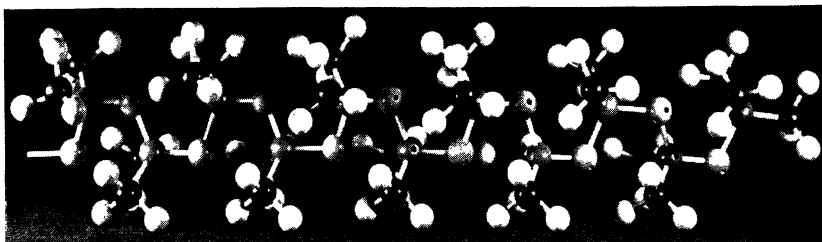
This is a complex process which is interesting primarily to chemists. The job of silicone chemists, and, to no little extent, their art, is so to "tailor" the high-polymeric organo-silicon oxide molecules that a variety of products, each designed to meet specific use requirements, can be produced.

Already a large group of new engineering materials have been derived from sand. These materials are available in a wide variety of physical forms. They include oils, compounds having a grease-like consistency, resins for heat-resistant enamels, laminates and molding plastics, and even a semi-inorganic rubber called "Silastic." In this age of chemical marvels, when people expect the chemist to pull new and ever more astounding marvels from under his hat, the production of rubber from sand is among the more astounding accomplishments of chemistry.

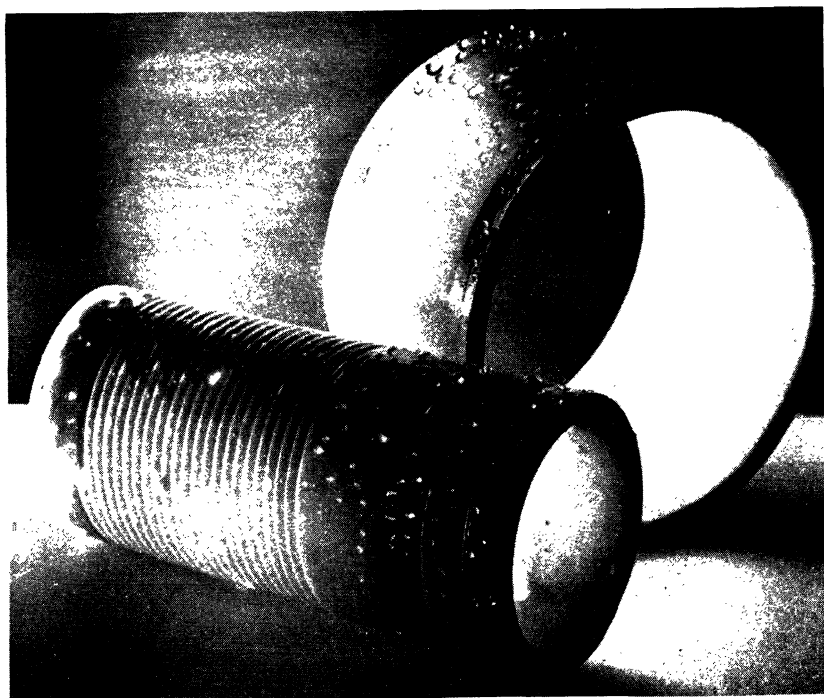
HEAT STABILITY

All these silicone products are characterized by a higher order of stability to heat and by greater resistance to moisture than conventional organic materials in the same physical forms. This heat stability and the suitability of silicone compounds for use in electrical insulation are inherent in their chemical structure. In the silicones, only two kinds of chemical bonds, the Si-O-Si and the C-Si bonds, are significant. The silicon-oxygen-silicon bonds are extremely stable to heat, as one would expect from the fact that these are the same bonds which exist in the mineral silicates. The carbon-silicon bonds also have a higher order of heat stability and greater resistance to oxidation than the carbon-to-carbon bonds which are basic in organic materials.

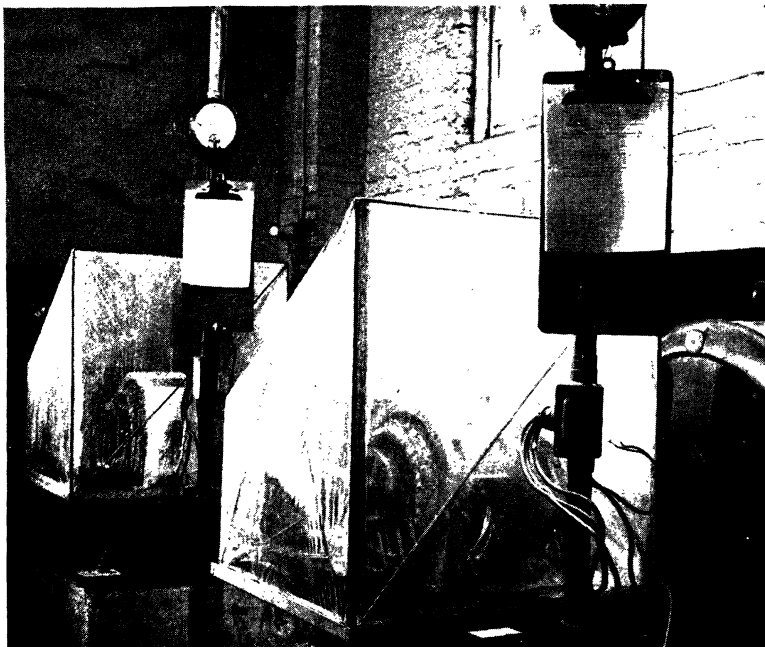
As a consequence of this greater heat stability, the silicone resins are natural complements to fibrous glass, mica, and asbestos insulating materials. The silicone resins provide the heat-resistant resinous dielectric necessary to bond these materials together. They also bond the insulating materials to the copper and steel used in building electric equipment. This bond is highly resistant to heat. It not only holds the insulation together, but also excludes moisture even after long exposure to high temperatures, as rigorous laboratory tests have shown. Thus, through the use of silicones together with inorganic insulating materials, a new type of electrical insulation has become available. This new class—silicone insulation—is almost immune to



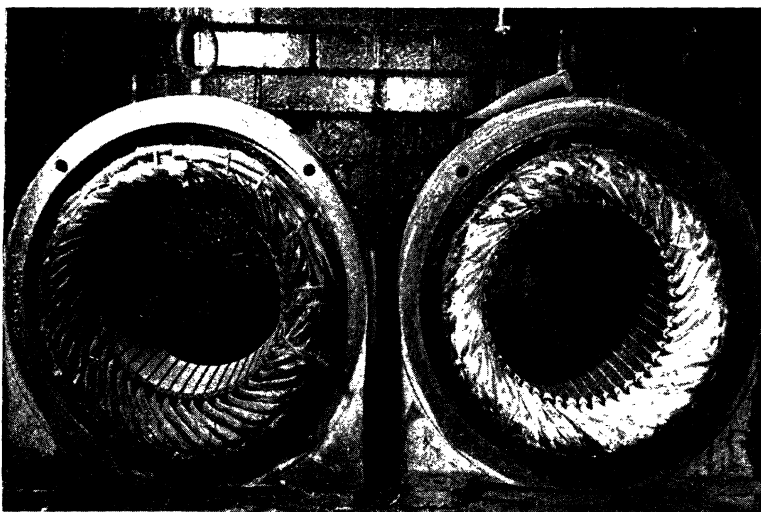
1. Model of a segment of a linear methyl silicone molecule.



2. The water-repellent nature of the silicones. Radio coil forms made water-repellent with silicone treatment. Their surfaces are nonconducting under moisture-condensing conditions.



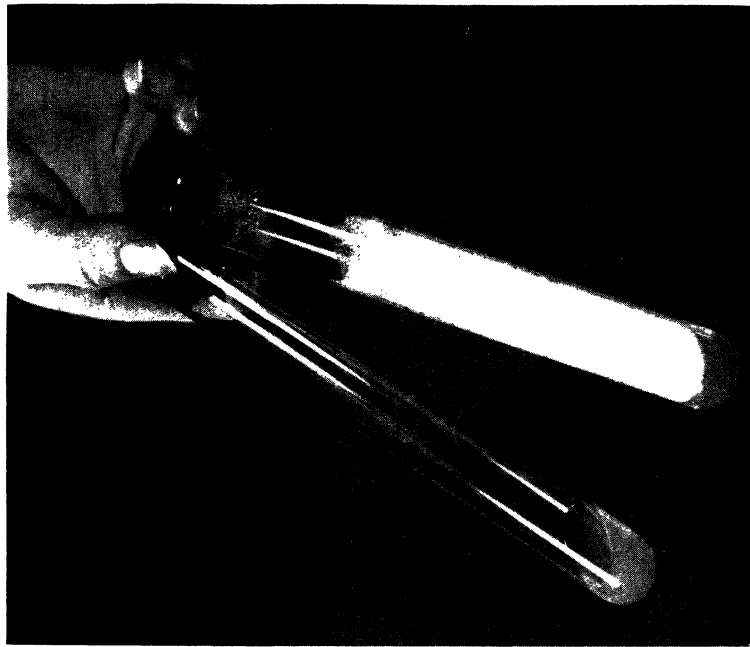
1. Silicone-insulated test motors are operated alternately at temperatures up to 310 degrees centigrade and exposed to 100 percent relative humidity. Tests show that moisture is excluded after thousands of hours of thermal aging.



2. Left, class B insulated motor failed after 3,760 hours at 200 degrees centigrade; right, silicone-insulated motor failed after 5,178 hours at 300 degrees centigrade. Both windings look about alike and show about the same degree of deterioration. The class B motor caught fire on failure, while the silicone-insulated motor failed because of oxidation of the copper.



1. Both motors operate at the same speed and deliver 10 horsepower. The silicone-insulated motor weighs about half as much as, and is half the size of, the larger motor.



2. The effectiveness of a silicone defoamer in killing foam in a rosin-soap solution.

heat and moisture, the principal enemies which conspire to reduce the life of electric equipment.

WATER REPELLENT

In addition to heat stability, other useful properties are inherent in the silicone chemical structure. All silicones are water repellent, and the methyl silicones are particularly so. The methyl silicone oils are long-chain structures of silicon atoms carrying two methyl groups each. The silicon atoms are joined to each other through an oxygen atom, the hydrocarbon portion of the molecule acting like a paraffinic umbrella for the rest of the molecule. Applied to the surfaces of glass or ceramic insulators, the silicon-oxygen-silicon portion of the molecule attaches itself to the surface, leaving the hydrocarbon portion upward. When water or moisture condenses on this surface, it does not do so in a continuous film, as in the case of an untreated glass surface, but in distinct droplets. This silicone treatment of insulators in radio sets, for example, prevents leakages across the surface because no continuous film of moisture forms a conducting path.

The waterproof property of silicones was utilized in a translucent and nonmeltable silicone paste, which proved to be quite essential to the proper operation of aircraft ignition systems and disconnectible joints in radar systems during the war. It served as an auxiliary dielectric and waterproofing seal for the ignition cable insulation where it entered the spark plug wells and magneto plugs of military aircraft. It prevented condensation of moisture at these points and kept the ignition system from being short-circuited. Another water-repellent application of silicone oils was initiated during the war and is still being developed—the production of a water-repellent filler made of fine glass fibers for use in life jackets and as thermal insulation.

STABLE VISCOSITY

One of the fundamental properties of long-chain silicone molecules is their resistance to associating with each other in ordered arrangement at low temperatures. These silicone fluids are characterized by an exceptionally flat viscosity-temperature slope. They do not thin out at elevated temperatures or thicken at low temperatures to so great an extent as do the petroleum fluids. Another manifestation of this property is found in the flexibility and resilience of silicone rubber at low temperatures. As a matter of fact, this silicone product retains its flexibility at temperatures only slightly above that of dry ice. Because of its heat resistance it is useful at temperatures up to 200° centigrade. It is, therefore, useful over a wider range of temperature than any other material having rubberlike properties.

INCOMPATIBLE WITH ORGANIC PLASTICS

Another useful property inherent in the fact that silicones are high-polymer molecules is their incompatibility with other plastic materials. A silicone fluid applied as a very dilute water emulsion spreads over the metal surface of dies to form an extremely thin film to which hot plastics and synthetic rubbers do not adhere. This property is of great value in the manufacture of tires and other molded-rubber articles. It is also useful in the molding of other plastic materials.

In the silicone fluids, various combinations of properties often lead to unexpected uses. For example, their incompatibility together with their surface effects at the interfaces of oil-air systems has been utilized to prevent the foaming of crankcase oils. Traces of silicone oil in petroleum oil are sufficient to prevent foaming.

Similarly, in aqueous systems foaming is often a serious and costly problem. A new silicone compound has recently been developed to prevent the foaming of aqueous systems or to kill foams once they have been formed. This product is effective at very high dilutions, varying from 1 to 100 parts per million.

In England the natural compressibility of certain silicon fluids has been utilized in a "liquid spring" hydraulic shock absorber that has been developed for use in aircraft landing gear. As the compressibility of the silicone fluids is 15 to 25 percent greater than petroleum fluids, the makers believe that the landing of heavier aircraft on present fields may be possible without increasing the size or weight of the landing gear.

The flat viscosity-temperature slope of silicone fluids together with their high flash point has led to an extensive study of their use as hydraulic fluids in aircraft by the Naval Research Laboratory, Washington, D. C.

This same flat viscosity-temperature slope of silicone fluids together with their shear resistance has led to the development of a torsional vibration damper for automotive crankshafts. In this device a free-wheeling flywheel floats in a film of silicone oil which damps any torsional vibration in the crankshaft.

In these applications some well-known engineering principles have been made practical for the first time. Correct in theory, these principles were not practicable until silicones were developed and proved to have the properties necessary to reduce theory to practice.

ECONOMY

There are very few established uses for silicone products which do not result in a considerable saving of time and money. An example is the speeding up of production and the reduction of rejects through the use of a silicone mold release in rubber molding. Silicone resins

may be used in formulating a more practical enamel for sheet steel used in domestic stoves. Another example is the saving of materials and the reduction of repair time in electric equipment which result from the use of silicone electrical insulating materials.

It is probable that the price history of most important new engineering materials will be repeated in the silicones. As volume increases, production costs should decrease, opening new fields of usefulness and larger volume markets.

FUTURE OF SILICONES

In this age of extremely high and low temperature operation, the unusual properties of silicone materials probably will become increasingly important. The last 2½ years already have demonstrated this with respect to the use of silicone insulation for electric apparatus. Actual tests of silicone-insulated electric equipment under severe and accelerated conditions of heat and moisture have shown that such equipment is capable of operating hundreds of times longer than conventional insulating materials. Manufacturers of motors, transformers, contactor coils, and other electric equipment are beginning already to standardize on silicone insulation in their lines. Maintenance and repair shops are rewinding an increasing number of motors with silicone insulation.

The silicone continent, nevertheless, is just beginning to be explored, and many years will be required to disclose the full extent of it.

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NEW PRODUCTS OF THE PETROLEUM INDUSTRY :

BY HUGH W. FIELD
The Atlantic Refining Co.

The headlines of the Nation's newspapers have been filled with accounts of the critical reconversion problems of most of our great industries. The petroleum industry, however, has been conspicuously quiet, yet it is well known that the wartime developments in this industry were tremendous. It is known that our forces, armed with mechanized equipment of a quality vastly superior to that of our enemies, never lacked the all-necessary petroleum supplies either in quality or quantity to do the critical job at hand. Very little is generally known of the nature of these war-born advances in petroleum refineries and their incorporation into a peacetime economy at a speed and efficiency that restored the motorist to a prewar basis almost overnight and will, we believe, shortly raise the standard of enjoyment of petroleum products well beyond all preconceived levels.

It is the purpose of this discourse to take you through the gates of the refinery and give you a first-hand glimpse of what has been happening during the last decade. The operations of petroleum refining have changed from those involving mainly rough physical separation by distillation to a complex well-integrated series of physical and chemical manufacturing operations involving the highest levels of modern chemistry and chemical engineering.

WHY THE PETROLEUM INDUSTRY GREW

In order to get a clear understanding of *what* has happened in our industry, it is necessary to understand *why* it has happened, and to accomplish this we will do well to look back into history to trace the development pattern. Fortunately, our browsing through history will not take long because the industry does not have much history as measured by years. Most of the significant items have occurred within the lifetime of those of us who are old enough to vote.

¹ Presented before The Franklin Institute, December 18, 1946. Reprinted by permission from the Journal of The Franklin Institute, vol. 243, No. 2, February 1947.

The petroleum industry has had its real growth along with two other young industrial giants, the automotive industry and the aviation industry. Further, although many of the new operations and products which will come into our story later seem to have little or nothing to do with either of these industries, the responsibility for much of what has happened is closely tied with their growth. It all began a little over 20 years ago when the automobile-engine designers stopped worrying about whether their engines would start and continue to run, and began to be worried by their sales departments for

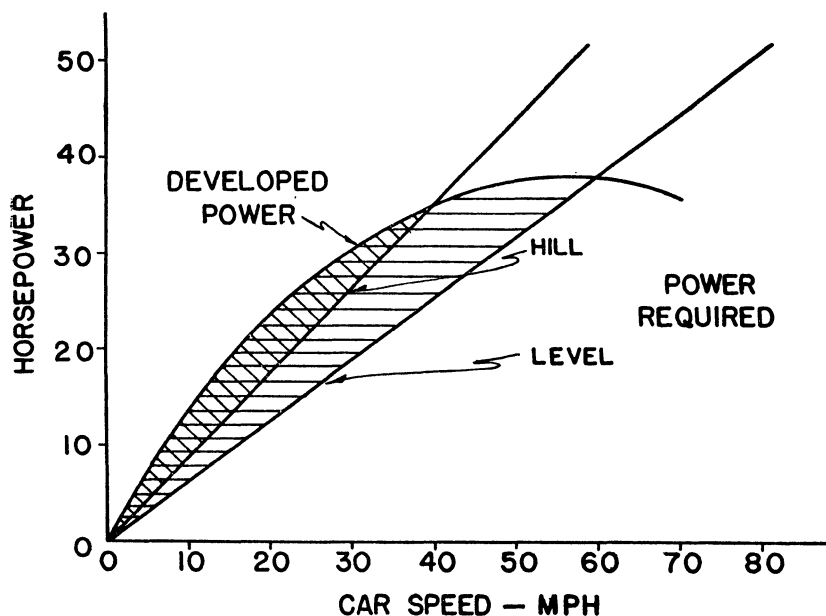


FIGURE 1.

promotional stories along the line of get-away, pick-up, hill-climbing ability, top speed, and so on. These designers studied their engines and their cars and found many interesting facts. Let us look into a few of these.

Figure 1 is a plot of horsepower against car speed for a typical car of the time operating in high gear. The curve depicts developed power as delivered to the rear wheels plotted against car speed. The straight lines approximate power required to move the car at corresponding speeds for level-road operation and for hill-climbing a reasonable grade. All conditions of wind, fuel quality, and loading were constant. It can be seen that this car has a top speed of 60 miles per hour on the level and has a reasonable amount of excess power for acceleration between the speed ranges of 15 to 50 miles per hour. However, on the hill the car speed will drop off to a top of 40 miles

per hour and will have practically no high-gear acceleration at lower speeds.

Figure 2 is the same basic plot with one additional curve, the developed-power curve for the same car with the same engine modified only by an increase in compression ratio from say 5.0 to 1 to a ratio of 6.0 to 1—a minor design change. Now the car has a top speed of 70 miles per hour on the level road and has good acceleration in the broader range of 10–60 miles per hour. More important, its hill-climbing ability is tremendously improved. On the same hill it can maintain a top speed of 55 miles per hour and below this speed shows

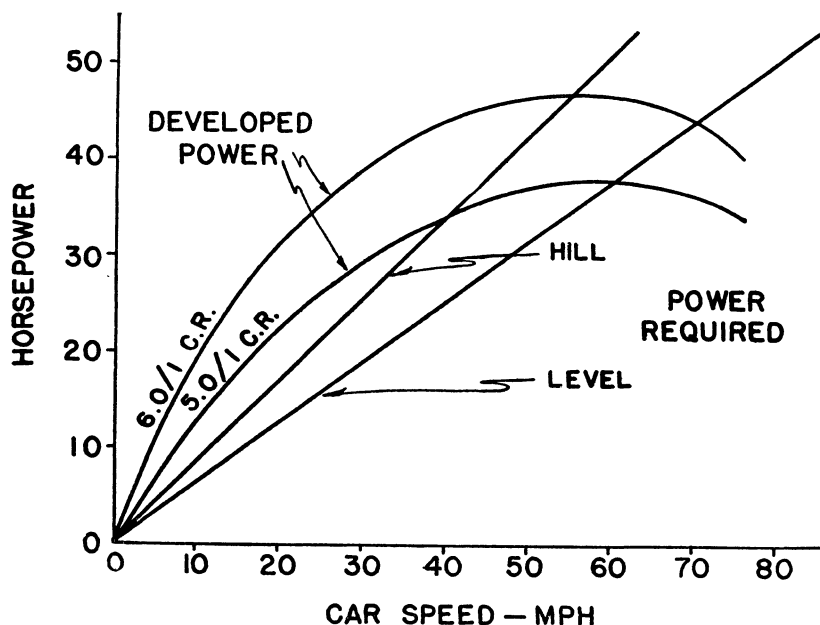


FIGURE 2.

acceleration characteristics approximately as good as the previous model showed on the level road. Here was a direction for the engine designer to go and he started off that way and moved rapidly until he was stopped short by the fact that at the higher compression ratios his engines began to knock badly under load, particularly after the combustion chambers became fouled with the carbonaceous deposits which inevitably appear after several thousand miles of operation.

Now let us look at what was happening in the refinery during this time. Initially, gasoline was the very volatile hydrocarbon material "topped" from crude oil prior to running for the kerosene fraction used extensively for cooking and illuminating purposes. The demands of the automobile for this gasoline rapidly took it out of the byproduct classification and the refiner was seeking ways and means of increasing

gasoline production. He had discovered the thermal "cracking" process with which, by the use of heat and pressure, he could convert a large portion of the fraction of crude oil between the kerosene and the lubricating oil cuts into gasoline. But this "cracked" gasoline fell into ill repute, largely because the refiner had not learned to finish it in such a fashion that it would not gum in the engine, resulting in sticking valves with attendant poor operation.

A comparison of notes by the refiner and the automobile designer brought out fundamental information which initiated the series of developments with which we are presently concerned. This information was that the knocking tendency of the higher compression automobile engine could be materially reduced or in some cases entirely eliminated by the use of the heretofore disfavored cracked gasoline in preference to the previously used straight-run gasoline, even though this straight-run material be cut to the extremely light old-time so-called high-test grade. Here was chemical synthesis of hydrocarbons appearing for the first time because very rough test methods, as then developed, showed that the cracked gasolines contained substantial quantities of olefins and aromatics, whereas the original crude oil contains few if any of these types of hydrocarbons. As a matter of interest, the earliest method of estimating the antiknock characteristics of motor gasoline came into being at this time. It matched the antiknock tendency of the fuel against known mixtures of benzol and Pennsylvania straight-run gasoline in a small single-cylinder laboratory engine and gave the results in terms of "benzol equivalent."

Two parallel series of developments were thus started in the refinery as a result of the move by the engine designers to higher compression motors. One series was aimed at removing or otherwise taking care of the then prevalent deficiencies of cracked gasoline with respect to gum-forming tendencies, chemical instability, and offensive odor. Processes to remove the gummy materials, soon identified principally as diolefins, from the cracked gasoline took the form of treatment with sulfuric acid and vapor phase treatment over activated fuller's earth. Further, various processes were developed to convert the malodorous mercaptans, which appeared in the gasoline as a result of an analogous cracking of sulfur compounds in the heavier cracking stock, into sweet-smelling alkyl disulphides, acceptable both to the public and to the motors. The result of these developments was the assumption by cracked gasoline of its rightful place as a desirable and important component of motor gasoline.

The other series of developments which raced ahead at this time had to do with the production of cracked gasoline itself. Literally scores of thermal cracking processes and variations thereof were invented and many of them were patented. As special methods of fabrication were developed and new steel alloys able to stand high

temperature for long periods became available, thermal cracking operations were pressed to higher and higher conditions of severity with respect to pressure and temperature. The severe cracking conditions produced more marked improvement in the hydrocarbon structure of the cracked gasoline. It had better antiknock characteristics.

At this point in our historical review the concept of "octane number" should be established. The previously used "benzol equivalent" was proving to be unreliable and not sufficiently reproducible for a test of a property which was becoming such an important characteristic of automobile gasoline. Benzol was so high in antiknock that it was too sensitive a blending agent and Pennsylvania straight-run gasoline, the zero of the scale by definition, was not invariable and reproducible. The octane-number scale was substituted instead and used as its "100" the chemical compound 2,2,4 trimethylpentane (isooctane), and as its "0" normal heptane. This scale was reproducible by blending these compounds and when coupled with the improvement and standardization of the test engine resulted in a more satisfactory fuel-rating procedure than had been heretofore available.

In the refineries of the country, aided by the advances in steel metallurgy, the antiknock characteristics of motor gasolines were being pushed to higher and higher levels as new units came on stream. Further, the use of additives for improvement of antiknock received extensive investigation. Various organic amino compounds were used with indifferent success to increase octane number. Iron and nickel carbonyls were more successful from the octane-number improvement standpoint but caused objectionable rust deposits within the engine. Finally, tetraethyl lead was discovered, proved satisfactory, and extensive manufacturing facilities were put into operation to help further the improvement in engine and fuel performance.

The "octane race" of the thirties was on in dead earnest. Automotive-engine designers moved their compression ratios higher and higher to get much more power and performance out of smaller engines. Figure 3 gives an interesting comparison for a representative passenger automobile. From this it can be seen that during the thirties the performance characteristics of the typical passenger car of approximately the same total weight improved considerably as a result primarily of the increase in compression ratio and the improvement in the quality of the motor fuel available for use in the higher compression engine.

At this point in our technical historical study, the issues become somewhat obscure as so frequently happens whenever history is reviewed, whether it be the history of people, cities, or nations. The automobile-engine designer had slowed in his advance to higher

compression ratio due to the fact that the motoring public was reasonably happy, if not somewhat unsafe, with the car performance being obtained. Added to this are the very practical facts that design difficulties were being encountered due to the necessity of allowing room in the engine head above the piston at the top of its stroke for the functioning of two valves and a spark plug and due also to a tendency to rough operation at high compression. However, the petroleum engineer was now in the saddle. He had many new processes all lined up to produce, and the refiner was now being urged by his sales-promotion people to produce qualities in gasoline that could be talked

YEAR	CAR	ENGINE		GASOLINE
	WEIGHT LBS.	COMPRESSION RATIO	BRAKE HORSEPOWER	OCTANE NO. REGULAR GRADE AVERAGE U.S.
1930	2930	5.15	64	60
1939	2934	6.32	85	71

FIGURE 3.

about. The result was that the petroleum refiners began to run races between themselves to produce gasoline with qualities outstripping their competitors in spite of the fact that scarcely any automobile engine could recognize differences in antiknock above its basic octane requirement. At the time, this race was scientifically invigorating but economically rather silly. In retrospect however, it was probably one of the best things that ever happened to our country in that it set the fundamental pattern for a technology that produced, during World War II, a stupendous tonnage of synthetic organic chemicals without which the war would have stretched through a much longer and more burdensome period.

EFFECT OF ENGINE AND FUEL DEVELOPMENT ON AUTOMOBILE DESIGN

Before proceeding further with the later developments in motor-fuel processing it will be well to stop to examine the results of all this

engine and fuel development work on the other parts of the automobile and on petroleum-product requirements for these parts. Increasing the power output of the engines produced greater loads on the engine connecting rod and main bearings with the result that many engine designers developed engines in which alloys of cadmium-silver and copper-lead were used for bearings instead of the conventional tin-lead (babbitt) which had been used heretofore. From the standpoint of bearing loads these materials were excellent but they immediately gave the petroleum refiners many headaches. The sulfur compounds present in the lubricating oil, the condensate from combustion chamber "blow-by" to the crankcase, and the acids produced by normal oxidation of the lubricating oil caused severe and rapid bearing deterioration. The corrosion attacked the lead and cadmium in these bearings, resulting in weakening of the bearing alloy, high wear, and early noisy operation of the engine.

Protection of these bearing materials was critical and the challenge to the petroleum research laboratories started a new trend in lubricating-oil development. This trend has resulted in the progressive addition to lubricating oils of a long series of additives. Initially additives were used to take care of bearing-corrosion problems. Later, additives were developed to add higher film strength characteristics. Presently, additives are being incorporated to furnish, in addition to the previous benefits, properties to prevent build-up of sludge deposits in the crankcase and to increase engine life heretofore shortened by internal rusting between periods of operation.

As engines increased in power and the streamlining of automobiles resulted in smaller wheels and lower floorboards, a redesign of the differential drive in the rear axle came about in efforts to lower the driveshaft to avoid the necessity for a tunnel in the rear floor. This gave rise to the use of hypoid gearing to drop the driveshaft below the center line of the rear axle. Hypoid gearing worked out very admirably from the standpoint of chassis design but necessitated an extensive amount of research in petroleum laboratories to develop a rear-axle lubricant for these new-type gears. The previous type of gearing, namely, spiral bevel gears, operated on the principle of rolling friction and a conventional heavy lubricant protected the faces of the gear teeth quite satisfactorily. The hypoid gear, on the other hand, operates on the principle of sliding friction and conventional lubricants could not give protection, with the result that the hypoid rear axles were scuffing severely because of failure of the oil to stay between the gear teeth. By the use of additives especially developed for the purpose, the oil companies quite promptly were able to furnish lubricants which had the proper combination of surface tension and wetting properties to stay in place on the gear teeth of heavily loaded hypoid gears.

The smaller wheels previously mentioned, the higher speeds resulting from greater engine power, and the general adoption of internal expanding four-wheel brakes raised another problem for the petroleum industry in lubricating the wheel bearings. The wheels were turning faster, creating higher operating temperatures in the bearing and greater centrifugal force which tended to throw the grease out of the bearings through the oil-retaining ring into the braking system to cause malfunctioning of the brakes. Grease compounding quickly received a complete overhauling in order to furnish a wheel-bearing lubricant which would maintain its consistency at high temperatures of operation, neither separating into oil and soap with resultant loss of oil and clogging of the bearing with soap, nor changing in physical characteristics as the temperature increased to a point where the grease would leave the bearing as the result of excessive softness.

General chassis lubricants also had to be restudied. All the previously mentioned developments were making cars run with less noise. Changes in spring-hanger design had increased the bearing loads on spring shackles so that there was an increased tendency for the shackles to squeak and with less noise competition the squeaks were more noticeable. New chassis lubricants were developed which could be pumped readily by the automatic chassis-lubricating equipment being installed in the service stations and would stay between the bearing surfaces in spite of heavy impact loading and the tendency for splashed water from the highway to wash this grease away. This particular development, incidentally, is probably one of the most ingenious feats of compounding that the industry has accomplished and is probably the least known generally.

CHANGING PETROLEUM REQUIREMENTS OTHER THAN AUTOMOTIVE

During this period under discussion the automobile, although acting as a pacesetter, was not the only requirement which was causing rapid changes in petroleum technology. The aviation industry, which had even more to gain from power from smaller engines, was stepping out ahead in requirements for high octane, high chemical stability fuel. The aviation-engine designer increased compression ratio with the attendant advantages previously discussed, reached the mechanical limitation to high compression posed by necessity for valve and spark plug clearances and engine roughness, and then moved on to even higher levels in antiknock requirements by adopting the principle of supercharging.

The supercharging approach to this problem is interesting and deserves further examination. If compression ratio cannot be increased readily, another way to get the same effect from a given engine is to pack more air and fuel into the cylinders by forcing it in under

external pressure, rather than letting the engine draw it in by the vacuum created on the suction stroke. This development, started mildly by the automobile designer and adapted mainly for racing-car engines, really went ahead at a tremendous pace when the aviation-engine designers started to use it. While the superchargers built for racing-car engines operated with only a few inches of water "boost pressure," the aviation-engine designer moved ahead to the point where, during World War II, combat aircraft equipped with exhaust-driven turbo superchargers actually delivered a boost pressure in the range of 60" of mercury or about 2 atmospheres increase. This development threw a tremendous burden on the petroleum industry for high antiknock fuel and, as will be mentioned later, the industry responded by adapting their newer processes and developing other specialized processes in order to produce the required volumes of aviation gasoline having performance characteristics well in excess of 100 octane.

Another type of engine was becoming important and giving the petroleum research laboratories critical problems to solve. This was the Diesel engine initially developed for propelling ships, later for long-distance truck hauling, and now becoming very important as a source of power for railway locomotives. The Diesel engine, unlike the gasoline engine, does not depend on a spark for ignition but depends on autoignition induced by the heat and pressure created by the compression stroke of the piston. It is a fact that an operating cycle of this type necessitates a chemical composition of the fuel distinctly different from the type of compounds which are included in motor gasoline and to a greater extent in aviation gasoline to improve antiknock characteristics. The latter have a decidedly deleterious effect on the starting and ignition qualities of the Diesel fuel, particularly for high-speed truck and railway Diesel engines. Thus a technical contrast is presented in which the best Diesel fuel was found to be a carefully refined fraction obtained directly from high-grade crude oil, whereas high-grade motor and aviation gasolines consist of a blend of various fractions of crude oil molecularly rearranged by severe thermal and catalytic cracking together with synthetic products of complicated structure obtained from alkylation, polymerization, etc.

Most of the comments made with respect to automobile-engine lubricating oil hold for lubricating the Diesel engine, except that whatever is done to the oil to improve its inherent characteristics must be greatly emphasized for the Diesel. Most high-speed Diesels run under much more severe conditions of loading, combustion roughness, and high-temperature operation than most automobile engines.

In industrial fields a new tempo of development has been evident.

Machine tools, industrial machinery, electrical equipment, heavy fuel oil consuming equipment, all have had their speeds, loads, and requirements for continuity of operation increased at a rapid pace. The petroleum industry has conducted research successfully to furnish petroleum products required to meet these demands. Complete details on the many ramifications of the changes in the petroleum industry's industrial requirements have no place in this review, but the order of magnitude of changes has been of the same degree as that depicted for automotive and aviation industries.

NEW PROCESSES WHICH LEAD TO NEW PRODUCTS

In 1939 the writer was requested to present to the Refining Division of the American Petroleum Institute a paper which attempted to systematize and catalog the many new processes which were under development at that time. This paper was somewhat whimsically entitled "Petroleum-ization—1940"² since it dealt with such previously little-known or unused processes as dehydrogenation, isomerization, polymerization, aromatization, alkylation, etc. The paper attempted to place these various new processes on the checkerboard of petroleum refining to determine which ones were competitive, which were complementary, and which should be considered for use as various refinery situations arose. Owing to the undeveloped state of some of these processes at that time, a large amount of forecasting based on personal opinion was woven into the pattern presented. However, subsequent events, specifically the war, forced the hasty commercialization of most of these processes substantially along the lines predicted and since this pattern is fundamental to our examination of new products it is presented here.

Definitions and descriptions.—A certain number of definitions and descriptions will be useful in our study of the situation; and if these definitions do not agree exactly with the organic textbook, it should be remembered that they were drafted for "petroleum-ization" rather than for the broad field of general organic chemistry.

Catalyst.—A catalyst can be defined as a substance which, although present during a chemical reaction, apparently does not enter into the reaction but causes, by its presence, a change in the conditions under which that reaction occurs. Thus catalytic reactions offer a possibility for product control by selective acceleration of certain reactions which, in the opinion of many, is the most important phase of this new refining technique.

Hydrogenation.—The hydrogenation process adds hydrogen to the hydrocarbon molecule. Hydrogenation may be either nondestructive or destructive. In the former, hydrogen is added to the molecule

² Proc. 20th Ann. Meet. Amer. Petroleum Inst., vol. 20, No. 3, pp. 65-71, 1939.

only if, and where, unsaturation with respect to hydrogen exists; thus the boiling range of the product is substantially the same as that of the charge to the process. In the latter, operations are carried out under conditions which result in rupture of some of the hydrocarbon chains (cracking), the hydrogen adding on, in general, where the breaks in the chain have occurred. A lowering of boiling range generally results from this type of hydrogenation, the degree of change depending on the operating conditions. Nondestructive hydrogenation is generally a low-temperature, low-pressure operation, whereas destructive hydrogenation operates at high temperature and high pressure. Catalysts are employed in almost all hydrogenation processes.

Dehydrogenation.—The general use of this term is so broad that it is practically useless. For example, the cracking of gas oil in an early batch still involved dehydrogenation. For the purpose of this discussion, the term will be limited to operations on material in the gasoline boiling range, or lighter, and considered in two categories, as was done for hydrogenation, i. e., nondestructive and destructive. Nondestructive dehydrogenation is defined as the removal of hydrogen from the hydrocarbon molecule without the cracking which would significantly change its boiling range. Destructive dehydrogenation removes hydrogen from the molecule, but is accompanied by chain rupture to some degree. Catalysts are employed for the nondestructive dehydrogenation, but the destructive dehydrogenation may be carried out either with or without catalyst, depending on the degree of selectivity desired.

Polymerization.—Broadly speaking, polymerization can be considered as the linking of two or more hydrocarbon molecules to form one molecule having a longer carbon chain and a higher boiling point. Here again the definition must be narrowed to make it useful, because the tar produced when gas oil is cracked in a conventional cracking coil is the result of polymerization. Polymerization, as practiced intentionally, at the present time is confined to hydrocarbons having four carbon atoms or less to the molecule (butane and lighter), and links them together under conditions which result in the product being predominantly within the gasoline boiling range. The operation can be carried out either catalytically or thermally. The catalytic process operates at relatively high pressures, but at moderate temperatures, and only the unsaturates in the charge react. The thermal process operates at high pressures and high temperatures, but both unsaturates and saturates react, owing in part, but not entirely, to thermal dehydrogenation taking place in the heating coil as the charge is brought to operating temperature.

Alkylation.—If any saturated hydrocarbon molecule is deprived of a hydrogen atom and then united with another hydrocarbon molecule

through the bond where the hydrogen atom was removed, alkylation has been accomplished. The broad definition of this term leaves us nowhere, but one of the specific alkylation processes in which interest is at a high pitch at the present time unites isobutane (a branched-chain compound) with a butane (unsaturated branched- or straight-chain compound) to produce practically pure iso-octane. The operation is carried out at low pressure and low temperature, and requires

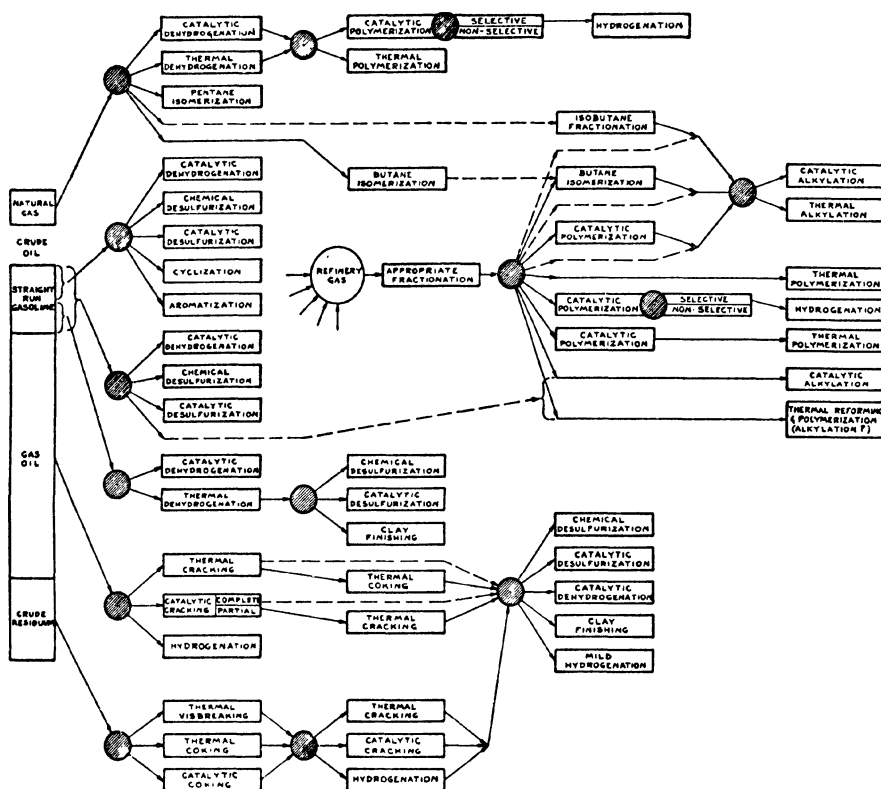


FIGURE 4.—Petroleum-ization—1940. Diagram indicates the complexity of the refiner's problem in properly selecting the processes for the several products and stages of refining best suited for his specific crudes.

a catalyst. Another example is the process which produces cumene. In this process propylene is reacted with benzol to produce isopropyl benzene, a valuable aviation blending agent.

Desulfurization.—In general, this term is self-defining, but here it will be considered as applying to the removal of sulfur from material within the gasoline boiling range. Chemical desulfurization, using either sulfuric acid or caustic soda, has been practiced for many years. There is, however, a definite feeling that destructive chemical desulfurization is on the way out; so, for the purpose of this summary—

which is concerned chiefly with the new catalytic processes—the definition will be narrowed to identify processes which decompose the sulfur-hydrocarbon compounds in the gasoline, and evolve the sulfur as hydrogen sulfide or possibly as sulfur dioxide.

Isomerization.—Inasmuch as saturated hydrocarbons can exist as either straight- or branched-chain compounds, and as the branched-chain compounds in the gasoline boiling range have higher antiknock qualities than the straight-chain compounds (e. g., iso-octane vs. normal heptane, the 100 and 0, respectively, of our antiknock scale), interest in controlled changing of straight chains to branched chains (isomerization) increased sharply as practicable methods were discovered. Isomerization, as now available for our study as an isolated process, is confined to butane and pentane conversion to the corresponding iso-compounds; but inasmuch as the extremely high octane-number increase obtained during certain catalytic-dehydrogenation operations on gasoline can best be accounted for by assuming some isomerization to have occurred, it is the opinion in many quarters that catalysts and conditions will be found eventually which will extend isomerization as a controlled process into the broad gasoline boiling range.

Aromatization.—For present purposes let us define aromatization as the conversion of saturated hydrocarbons to aromatic hydrocarbons, e. g., conversion of hexane to benzol, heptane to toluol, etc. Processes using catalysts at relatively high temperatures and moderate pressures have accomplished such conversions with surprisingly high yields.

Catalytic cracking and reforming.—As mentioned previously, cracking involves dehydrogenation of the type defined as destructive. In the rupturing of the hydrocarbon chains, there are created fragments which are extremely active chemically. In the course of reacting to attain chemical stability, these fragments apparently, to some degree, engage in practically all of the reactions which we have been discussing. The use of a catalyst during cracking has the interesting effect of decreasing the amount of polymerization to tar and at the same time encouraging aromatization and isomerization of the cracked fractions into the gasoline boiling range. As a result, material of high antiknock value is produced. In catalytic reforming a different effect is sought. Here aromatization and isomerization are encouraged by different operating conditions and catalysts, but every effort is made to suppress the chain rupture which would cause excessive conversion of gasoline to gas. In figure 4 catalytic reforming is classified as dehydrogenation, but merely for convenience, and does not infer that the dehydrogenation phase is considered predominant.

Coking.—The operation of coking, whether thermal or catalytic, consists of heat-treating heavy hydrocarbons, usually crude residuum or cracked tar, in order to increase the ultimate yield of gasoline from

the crude. Heavy hydrocarbons are low in hydrogen-carbon ratio; gasoline is relatively high in this same ratio. The conversion, therefore, necessitates the throwing out of carbon (coke) as a means of adjustment of this ratio. Catalytic coking, as contrasted with thermal coking, results in less coke "throw-out" for a given conversion, possibly due to the fact that gasolines of relatively high aromatic content have a lower hydrogen-carbon ratio than nonaromatic gasolines, and lower carbon "throw-out" would suffice for the adjustment in hydrogen-carbon ratio necessitated by this type of conversion.

Figure 4 is taken directly from the above-mentioned paper.³ This scheme starts with crude petroleum and presents some of the various courses which might be charted in converting this crude oil to gasoline as the major product, the shaded circles representing positions in a stepwise examination where a stop is made to review ways and means before taking the next step.

A quick review of this chart shows that the first step for most of the operations in refining crude oil to high octane gasoline, is that in which the hydrocarbon fractions existing in the crude oil as received are changed in molecular structure from chemically stable hydrocarbons to materials which are chemically reactive and are thus susceptible to synthesis into highly branched chain materials which have been found to have the higher antiknock values. Upon completion of whatever synthesis methods are used, either thermal cracking, thermal or catalytic dehydrogenation, polymerization, or alkylation the materials thus produced may be satisfactory for blending into motor fuel directly as such, or may require further treatment such as hydrogenation or desulfurization.

COMBAT-GRADE AVIATION GASOLINE

In 1939 very few plants were operating dehydrogenation, polymerization, alkylation, or hydrogenation units. During the war the requirements for combat-grade aviation gasoline posed a problem in large-scale production of isopentane, iso-octane and the other trimethylpentanes, alkylated aromatics, and carefully fractionated and prepared catalytic base stocks to be blended into finished fuel. It was only by tailormaking the fuel in this fashion that the characteristics required by the modern aviation engine could be met completely. The fuel had to be 100 octane under normal cruising conditions, it had to be chemically stable under storage conditions in all parts of the world, and it had to respond with an apparent antiknock value considerably in excess of 100 to permit a heavily loaded plane to take off with maximum power at top supercharge boost pressure and rich mixture conditions.

³ Petroleum-ization—1940.

The important development of catalytic cracking enabled the production of superior aviation base stocks. In these processes, the presence of a catalyst results in the formation of appreciable quantities of isoparaffins and aromatics. Only a very small amount of olefins, which are undesirable for aviation gasoline, are formed in contrast to older thermal cracking processes which produce large amounts of olefins.

Three chief sources of isoparaffins were utilized. The most important was the product known as "alkylate," which is produced by combining low molecular weight olefin and isoparaffin hydrocarbons. The second was the polymerization of two low molecular weight olefins (product known as codimer) followed by hydrogenation to obtain an isoparaffin. The third was the rigorous fractional distillation of straight-run stocks. To meet military demands all these processes were perfected and expanded.

The need for aromatic hydrocarbons immediately imposed another synthesis problem since benzene, the most readily available aromatic, freezes at 40° F. and cannot be used to any great extent because aviation gasoline must meet low-temperature requirements for high-altitude flying. Consequently, cumene (f. p., -141° F.) was immediately synthesized by alkylating propylene (a waste refinery gas) and benzene and became the first important source of aromatics for aviation fuel. It is interesting to note that cumene had never been produced commercially before the war but by the end of the war about 500,000 gallons per day were in production. Other sources of aromatics were xylenes and toluene both synthesized from petroleum and excess ethyl benzene from the synthetic-rubber program. The fact that some of these aromatics were produced by alkylating benzene with olefins (cumene and ethyl benzene) while others were made by dehydrogenation of cycloparaffins illustrates the versatility used to achieve results.

The old source of pentanes used for volatility did not escape examination and these ultimately were separated and only the isopentanes used. The chemical "aviation gasoline" near the close of the war had the following composition, listed in approximate order of increasing boiling range:

Isopentane

Isoparaffins:

Alkylate

Hydrogenated codimer

Isohexanes and isoheptanes (fractioned from straight-run naphtha)

Aromatics:

Toluene

Xylenes

Ethyl benzene

Cumene (isopropyl benzene)

Catalytic cracked base stock

This mixture of components with the addition of tetraethyl lead was known as 100/130-grade aviation gasoline. It has a performance rating of 130 under take-off conditions and a rating of 100 under flight conditions. This fuel made available 30 percent more power over the old fuel for take-offs and short bursts of speed during actual combat. At the start of the war the production of 100-octane aviation gasoline was approximately 40,000 barrels per day. At the close of the war 100/130-grade aviation fuel was being produced in excess of 500,000 barrels per day.

INDUSTRIAL PROCESSING MATERIALS FROM PETROLEUM

In the field of what are known as processing materials from petroleum there continue to be new products and applications. In fact there are few articles that do not utilize petroleum in some form in their manufacture. It is said that over 30 basic industries employ petroleum in their manufacturing operations. Individual applications are numerous. It is in the classes of processing materials and manufactured chemicals that petroleum products number into hundreds and unit values are greatest.

One of the processing materials made from petroleum in largest volume is paraffin wax with which we are all familiar as a component of bread wrappers, waxed paper, paper milk bottles, and candles.

A newcomer to the field of waxes is a material known as microcrystalline wax which is tough and pliable at low temperatures and extremely resistant to water. Microcrystalline waxes had been made prior to the war but their real value was not appreciated until the advent of problems created by the war. They were first called "amorphous waxes" because they were believed to be noncrystalline. Later it was found that they contained minute crystals and the name microcrystalline waxes came into use. Small arms and rations were packaged in containers utilizing these waxes in their construction. They have also been used for liners of metal cans and drums to resist the action of beer, wines, and acids. The developments in these waxes created large demands and it is necessary for the industry to bend every effort to supply the required quantities.

In most uses of petroleum waxes, they are applied in a molten condition. Wax can also be applied in the form of a wax emulsion which is a suspension of fine wax particles in water, with a suitable dispersing agent. The use of wax emulsions is attaining increased importance. The armed forces used thousands of yards of tent cloth, cotton duck, and mosquito netting that had been treated with wax emulsion to impart a water repellent finish to the individual fibers. The treatment has practically no effect on the appearance and "feel" of the fabric

and because of openings remaining between the fibers, adequate ventilation is assured.

Rust preventives are another group of products designed for war service. Protection against rust has always been a problem but it was made more difficult by military requirements. Metal objects both large and small had to stand shipping on boats all over the world where exposure to salty air and high humidity was ideal for rapid rust formation. Practically all metal articles used by the armed forces were coated with one of many rust preventives developed, and in many instances the rust preventive was subsequently removed before use of the article, adding to the problem. Practically all these rust preventives contained a petroleum base. The knowledge gained here should find ready application in preserving metal machinery such as farm tools and machinery frequently stored for long periods without use.

Two new developments in the field of asphalt are prefabricated airport runways and asphalts which will satisfactorily coat wet stone. In the first development burlap is saturated with asphalt, coated with small stones and rolled up as is common asphalt roll roofing for shipment. It is put down by employing a 50 percent overlap and cementing together with an asphalt cut-back. A large amount of this was employed by the armed forces.

The nonstripping type of asphalt contains additives which increase its adhesion to stone, even if applied when the latter is wet. Roads may thus be laid in rainy weather and in addition give better and longer service.

Other developments in processing materials derived from petroleum include plasticizers and softeners for synthetic rubbers, special oils that are heavier than water for mosquito control, and high refractive index oils for use in examining quartz crystals which are cut into oscillators to control wave length in radar and radio equipment.

SYNTHETIC RUBBER FROM PETROLEUM

Much has been written about this country's synthetic-rubber industry, claimed by some before the atomic bomb announcement to be the greatest technical achievement of all time. Large quantities of butadiene and styrene were needed to make the Government's all-purpose rubber known as GR-S. There are several methods of producing butadiene from petroleum but the best method consists in dehydrogenating certain C_4 hydrocarbons to form butadiene. As an example of the commercialization of butadiene production the Government-owned plant of the Neches Butane Products Company producing butadiene from petroleum is rated at 100,000 tons of butadiene per year and has produced at a rate far in excess of this. New uses for butadiene can be expected now that this material is commercially

available, and at least one such product (butadiene monoxide, a chemical intermediate) has already been announced.

Styrene production also required for GR-S rubber is carried on by the chemical industry by alkylating benzene with the petroleum olefin ethylene to form ethyl benzene which is converted to styrene by dehydrogenation. Ethylene is recovered from refinery gases or produced by cracking a petroleum hydrocarbon such as propylene.

Butyl rubber, another very important synthetic rubber, is a 100-percent petroleum product and a 100-percent American development. It is synthesized from isobutylene, a petroleum hydrocarbon obtained from cracking processes, and a small amount of a diolefin such as isoprene. These two hydrocarbons are converted into butyl rubber at temperatures of approximately -150°F . by a continuous process. This development filled the nation's need for heavy-duty inner tubes at a critical time, since GR-S (butadiene styrene rubber) is unsatisfactory and natural rubber was cut off. Butyl rubber in some respects is superior to the latter in having better resistance to oxidation and lower permeability to the passage of gases. Inner tubes from it have proved superior to those of natural rubber. This product is expected to have an excellent future. It should find new uses in electrical insulation, waterproof fabrics, and mechanical goods.

PLASTICS FROM PETROLEUM

In the field of plastics there have been some notable products derived from petroleum hydrocarbons. Among the newer petroleum plastics are polyethylene resins, allyl plastics, and polyvinylidene chloride resin. Polyethylene resins are a 100-percent petroleum hydrocarbon resin produced by polymerizing ethylene itself. Their production was announced in 1944 by the duPont Co. and then independently by the Carbide & Carbon Chemicals Corp. Polyethylene plastics are flexible and tough over a wide range of temperatures, have exceptional electrical properties, are resistant to moisture penetration, and are chemically inert. They are thermoplastic and can be made into thin sheets and filaments. Polyethylene has been used primarily in electrical insulation for radar equipment. It can be expected to find many uses in a peacetime economy. Its production represents another major technical achievement.

Allyl plastics are based on allyl alcohol which is derived from propylene. In 1942 two allyl resins were announced, one (diallyl phthalate) by an oil company and the other (now allymer CR-39) by a chemical company. These plastics are reported to make excellent coating materials for cans and metal containers, one being reported to be less brittle and harder than glass and harder than any other transparent plastic. Its uses have been strictly military. These resins have properties unique to themselves which should make them

find ready markets. Allyl alcohol and chloride will doubtless find many other uses in chemical synthesis.

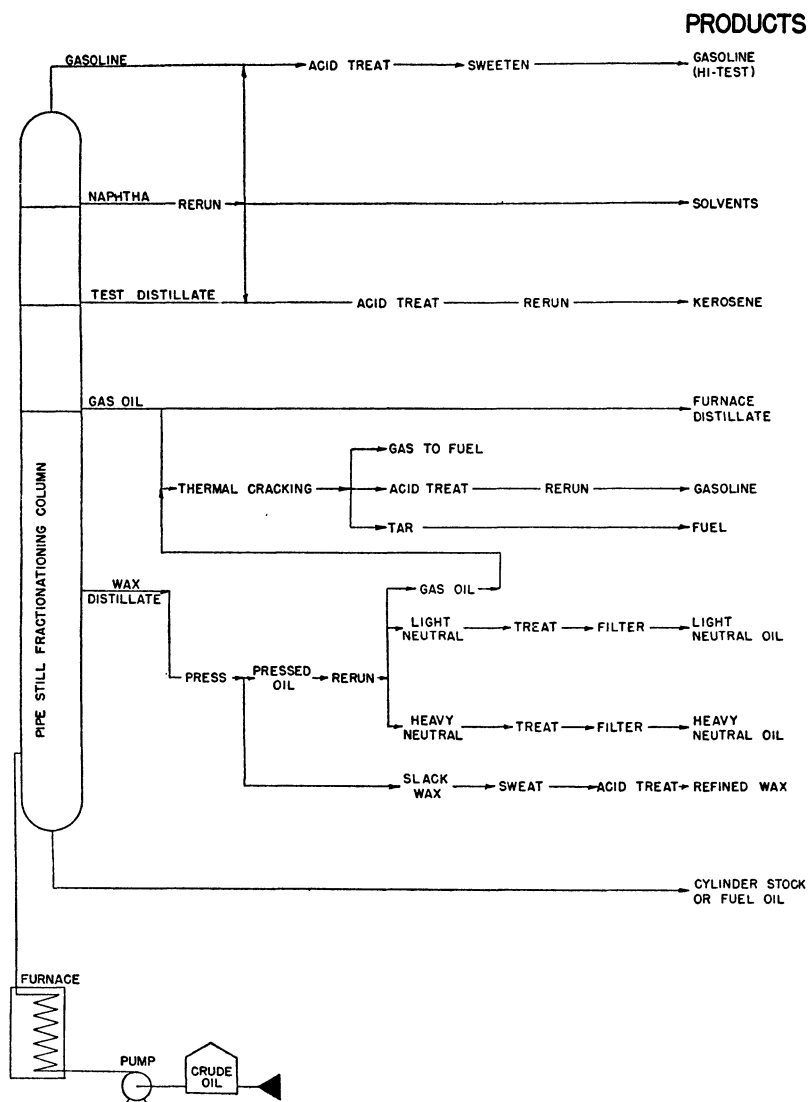
Some time ago a chemical company announced a resin produced from the monomer vinylidene chloride which is a derivative of ethylene and is therefore of interest to the petroleum industry. It differs from the older vinyl chloride monomer in that two chlorine atoms have been substituted for hydrogen atoms in the ethylene molecule instead of one. This plastic is very tough and resistant to solvents, has a very high tensile strength and can be made into strong filaments. Taking advantage of these properties, expected uses include seat covers, filter cloths, house screening, fishing lines, hose connections, and flexible tubing.

Older resins which are derived at least in part from petroleum and were greatly expanded for war uses are the polyvinyl resins, acrylic resins (Lucite and Plexiglass), ethylcellulose, and phenolics employing alkylated phenols.

Among important chemicals newly derived from petroleum and announced during the war is phthalic anhydride, produced by oxidizing orthoxylyene (previous production has been from naphthalene from coal tar). One petroleum company has built a plant to manufacture this chemical which is used in the synthesis of plastics, plasticizers, and insect repellents. Another company has announced a new synthesis of carbon bisulfide from methane and sulfur. This chemical is used in the manufacture of viscose rayon, solvent extraction processes, and in the manufacture of chemicals used in ore separation and for vulcanizing rubber. Its older synthesis was from coke and sulfur.

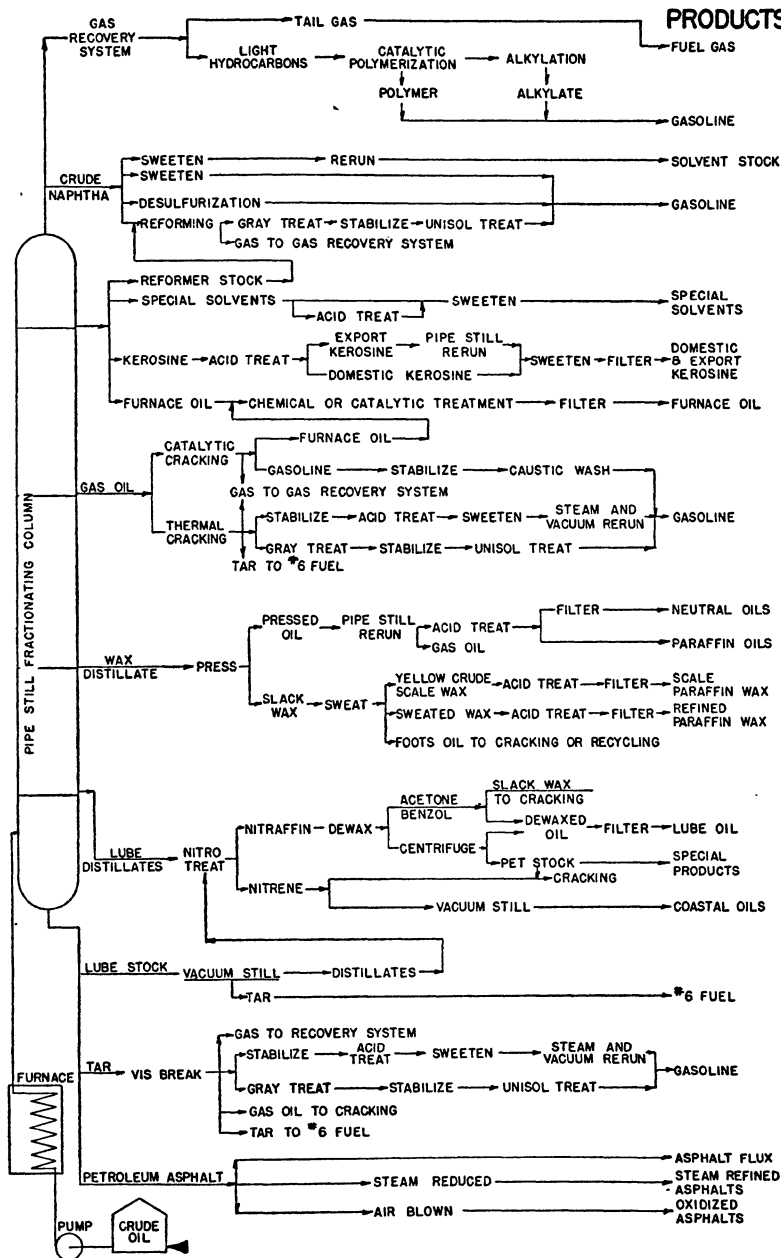
DETERGENTS FROM PETROLEUM

For many years both oil-soluble and water-soluble soaps have been produced from petroleum mainly as byproducts from the treating of oils for industrial or medicinal purposes. Just prior to the war a demand arose for synthetic detergents or wetting agents which would be superior to either the byproduct soaps or those made by saponification of fatty or vegetable oils. Research carried out in petroleum laboratories resulted in development of processes for synthesizing such detergents from petroleum hydrocarbons, and commercialization of these processes was quite rapid. During the war all such production was under allocation to such uses as incorporation in GI all-purpose soap for use in all kinds of water, penicillin manufacture, and many other critical uses. Since the war, requirements have increased largely through the use in industrial and household cleansers. In addition, many of the products have been improved by utilizing plant facilities and processes developed for aviation-gasoline or toluene manufacture. The petroleum soap of today is a complicated chemical synthetic



FLOW DIAGRAM CRUDE OIL REFINING, 1926

FIGURE 5.



FLOW DIAGRAM CRUDE OIL REFINING OCT., 1946

FIGURE 6.

controlled in properties to meet very exacting requirements and a far cry from the older types of byproduct soap.

WHAT HAS HAPPENED TO THE REFINERY

As we have traced refinery history in the preceding discussion many new processes have been developed to handle the requirements for the many new and improved petroleum products now in demand. The process flow of a refinery has become almost a maze. Figure 5 depicts a typical refinery flow, corresponding in chronology approximately to the start of our historical survey. Without commenting on the details the main thing to note is the relative simplicity of processing and number of products.

Figure 6 depicts a typical refinery flow today, without including the details of some of the previously mentioned complex chemical processes. A comparison with the preceding figure explains why present-day refineries must be heavily staffed with technically trained personnel and must operate hand in hand with large and competent research and development departments. Today a petroleum refinery is not only that but has also become a large-tonnage chemical manufacturing plant; and we are still going strong.

CONCLUSION

In conclusion it can be said that the petroleum-refining industry has in either active or contemplated production materials used in:

- Alcohols and antifreezes,
- Lacquers, paints, varnishes, and solvents,
- Rayons and plastics,
- Dyestuffs, textile oils, and leather oils,
- Synthetic rubbers and paper,
- Medicines, poisons, and toilet goods,
- Explosives and anesthetics,
- Detergents, emulsifiers, and wetting agents,

in addition to bottled household fuel gas, motor fuels, kerosene, furnace oil, lubricants, and heavy fuel oils which are generally considered the refiner's main stock in trade. Does it seem strange to hear that coal is hauled to market by a Diesel oil engine?

Thus refining is rapidly becoming a broad and versatile chemical-manufacturing business and the refinery chemist has reason to believe that he can derive from oil practically every hydrocarbon that can be derived from coal, many products now or formerly derived from vegetable and animal materials, and many products that cannot be obtained on commercial scale from any of these sources.

The last 10 years of petroleum-refining developments have been interesting and exciting, and rapid obsolescence of processes and products has given truth to the statement that "there is no such thing as an up-to-date refinery" since it will be obsolete, at least in part, before it can be completed.

THE TSUNAMI OF APRIL 1, 1946, IN THE HAWAIIAN ISLANDS¹

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[With 6 plates]

INTRODUCTION

The tsunami which struck the shores of the Hawaiian Islands on the morning of April 1, 1946, was the most destructive, and one of the most violent, in the history of the Islands. More than 150 persons were killed, principally by drowning, and at least 161 others were injured. Property damage reached about \$25,000,000.

The wave attack on Hawaiian shores was far from uniform. The height and violence of the waves at adjacent points varied greatly, and not always in the manner which would have been expected from superficial inspection and a study of the existing literature on tsunamis. Therefore, a detailed study of the effects of the tsunami has been made, in an effort to understand the observed variations, and in the hope that the principles established may help lessen the loss of life and property in future tsunamis. Space is not available in the present short paper to discuss findings in detail, or even to present all the evidence for all the conclusions. These matters will be treated in detail in a longer paper (Shepard, Cox, and Macdonald, in preparation).

Acknowledgments.—We wish to thank the many persons who furnished information during the course of the field study. We are also especially grateful to M. H. Carson, H. S. Leak, H. W. Beardin, and W. K. Sproat, who supplied measurements of the highwater level in areas not visited by us; H. W. Iversen and J. D. Isaacs, who supplied additional measurements on Oahu; A. F. Robinson and Dexter Fraser,

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who furnished descriptions of the wave effects on Niihau and Lanai, respectively; the Hawaii County engineer's office, which supplied a map showing the extent of flooding in Hilo; and the United States Coast and Geodetic Survey, which supplied data on the earthquake and the record of the Honolulu tide gage, and permitted the use, in advance of publication, of C. K. Green's manuscript on the tsunami along the shores of North and South America. Howard A. Powers, seismologist of the Volcano Observatory at Hawaii National Park, aided greatly in the investigation on the island of Hawaii. Miss Maude Jones, archivist of the Territory of Hawaii, and Miss Margaret Titcomb, librarian of the Bishop Museum, aided in locating records of past waves. C. K. Wentworth and H. S. Palmer aided greatly in discussions. Wentworth and Walter Munk read and criticized the manuscript. J. Y. Nitta prepared the illustrations.

DEFINITION OF "TSUNAMI"

The name "tsunami"² is applied to a long-period gravity wave in the ocean caused by a sudden large displacement of the sea bottom or shores. A tsunami is accompanied by a severe earthquake, but the earthquake does not cause the tsunami. Rather, both are caused by the same sudden crustal displacement. The waves of a tsunami have a period of several minutes to an hour as contrasted with several seconds for ordinary storm waves caused by wind, a wave length of scores of miles as contrasted with less than 500 feet for wind waves, and a speed of hundreds of miles an hour as contrasted with less than 60 miles an hour for wind waves. Tsunamis are also sometimes termed "seismic sea waves," and are popularly known as "tidal waves." The latter term is patently undesirable, as the waves have no connection whatever with the tides. "Tsunami" is used herein in preference to "seismic sea wave" because of its greater brevity, and because the etymological correctness of the term "seismic sea wave" appears open to question.³

HISTORY OF TSUNAMIS IN HAWAII

Tsunamis probably reach Hawaiian shores on an average of more than one a year. Most of these are small, however, and generally escape notice except when their record is recognized on tide gages. Earlier tsunamis in Hawaii have been discussed by Jaggard (1931)

² Also spelled "tunami," the Japanese equivalent of the letter "t" being pronounced "ts" in English. It appears preferable, however, to use the phonetic spelling in English, avoiding thereby much incorrect pronunciation.

³ The adjective "seismic" is derived from the Greek root *seismos*, meaning earthquake, and is defined as pertaining to, produced by, or characteristic of an earthquake. The waves in question are not, however, characteristic of most earthquakes, even those of submarine origin, and are not produced by earthquakes.

and Powers (1946, p. 3). The accompanying table lists all the tsunamis noticed on Hawaiian shores, in the period of written history, of which record could be found, together with their sources if known. A total of 27 are listed, or an average of 1 every 4.7 years since 1819. Most of them, however, did little damage. During the same interval

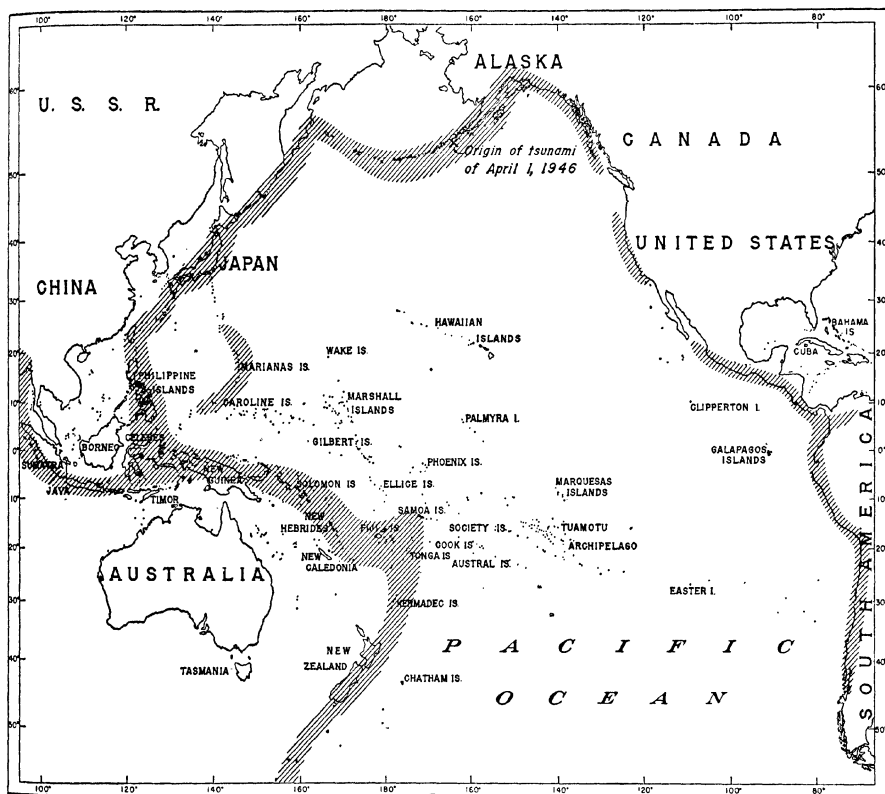


FIGURE 1.—Map of the Pacific basin, showing the position of the Hawaiian Islands, the place of origin of the tsunami of April 1, 1946, and the distribution of seismically active belts around the Pacific in which tsunamis are likely to originate.

there are listed five severe tsunamis which caused extensive damage, an average of one every 25.6 years.

Other violent waves have been termed "tidal waves" in the newspapers, but were more probably storm waves. Such were the waves which hit Maliko, Maui, on January 28, 1895, and those which struck Kaunapali on Lanai, and Nawiliwili on Kauai, on May 30, 1924.

It will be noted that only 2 of the 27 tsunamis listed in the table were of local origin. With the exception of the numerous volcanic earthquakes on the island of Hawaii, which seldom cause tsunamis, the Hawaiian region is only moderately active seismically (Gutenberg

and Richter, 1941, pp. 84-85). The great majority of the tsunamis reaching Hawaii originate in the highly seismic border zone of the Pacific. Of the 22 tsunamis from known sources listed in the table, 5 came from near South America, 1 from near Central America, 1 from near California, 3 from near Alaska and the Aleutian Islands, 5 from near Kamchatka, 3 from the Japanese area, and 1 from near the Solomon Islands. Of the five severe tsunamis, three originated near the coast of South America and one in the Aleutian area, and one was of local origin. One tsunami of moderate intensity came from near Kamchatka, and another probably from South America.

TABLE 1.—*Hawaiian tsunamis*

Date	Source (nearest coast)	Damage in Hawaii	Average speed of waves
			<i>Mi. per hr.</i>
1819, Apr. 12	Unknown	Unknown	.....
1837, Nov. 7	South America	Severe	.....
1841, May 17	Kamchatka	Small	.....
1868, Apr. 2	Hawaii	Severe	.....
1868, Aug. 13	South America	do	.....
1869, July 25	South America (?)	Moderate	.....
1872, Aug. 23	Hawaii	Small	.....
1877, May 10	South America	Severe	.....
1883, Aug. 26	East Indies	Small	.....
1896, June 15	Japan	None	 478
1901, Aug. 9	Japan (?)	do	.....
1906, Jan. 31	Unknown	do	.....
1906, Aug. 16	South America	Small	.....
1918, Sept. 7	Kamchatka	do	 456
1919, Apr. 30	Unknown (distant)	None	.....
1922, Nov. 11	South America	do	 450
1923, Feb. 3	Kamchatka	Moderate	 432
1923, Apr. 13	Kamchatka	None	 438
1927, Nov. 4	California	do	 462
1927, Dec. 28	Kamchatka	do	 438
1928, June 16	Mexico	do	 462
1929, Mar. 6	Aleutian Is.	do	 492
1931, Oct. 3	Solomon Is.	do	 447
1933, Mar. 2	Japan	Small	 477
1938, Nov. 10	Alaska	None	 496
1944, Dec. 7	Japan	do	 425
1946, Apr. 1	Aleutian Is.	Severe	 490

GENERAL FEATURES OF THE APRIL 1946 TSUNAMI: ORIGIN AND NATURE OF THE WAVES

The tsunami of April 1, 1946, was caused by a movement of the sea bottom on the northern slope of the Aleutian Deep, south of Unimak Island. The same crustal movement gave rise to a violent earthquake, recorded on seismographs all over the world. In Hawaii it was recorded on the instrument of the United States Coast and Geodetic Survey located on the campus of the University of Hawaii in Honolulu, and on those of the Hawaiian Volcano Observatory at Kilauea on Hawaii. The epicenter of the earthquake has been located by the Coast and Geodetic Survey at latitude 53.5° N. and longitude 163° W., and the time established as $1^{\text{h}}59^{\text{m}}$ a. m. Hawaiian time ($12^{\text{h}}29^{\text{m}}$ Greenwich time) (Bodle, 1946, p. 464). It may be assumed that the tsunami originated at the same place and time as the earthquake. The

place of origin was thus 2,241 miles N. 8.5° W. of Honolulu, and 2,375 miles N. 12° W. of Hilo (fig. 1).

The time of arrival of the waves in the Hawaiian Islands is known with certainty only at Honolulu. The record of the Honolulu tide gage (fig. 2) shows that the first rise started at about 6:33 a. m. (C. K. Green, 1946, p. 491), though the exact time cannot be stated closer than 2 or 3 minutes. The drum of the water-stage recorder at the Waimea River, on Kauai, revolves too slowly to give an accurate indication of time, but the first rise appears to have started there at about 5:55. At Hilo, electric clocks were stopped at 7:06, and a

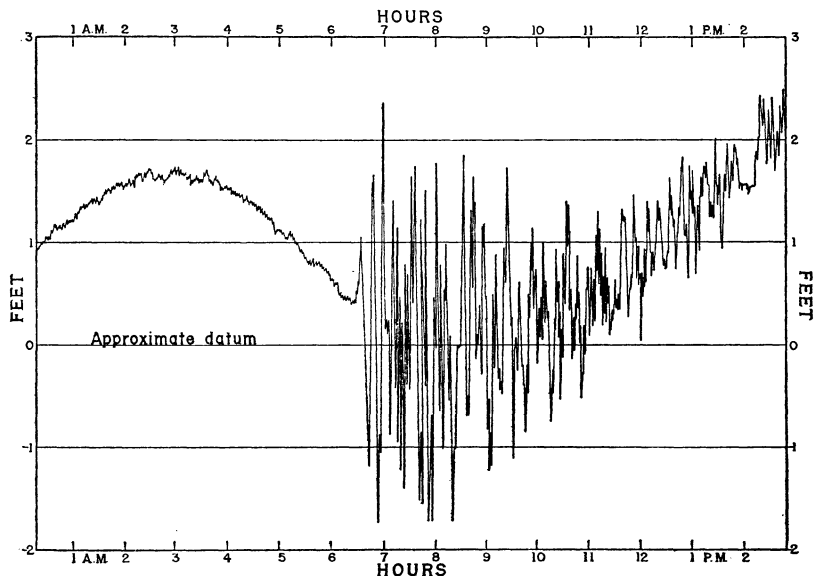


FIGURE 2.—Record produced on the tide gage in Honolulu Harbor by the tsunami of April 1, 1946.

brief power failure occurred at 7:18. These have been interpreted by Powers (1946, p. 2), probably correctly, as the time of arrival of two wave crests at Hilo. From other considerations, discussed briefly elsewhere (Shepard, Macdonald, and Cox, in preparation), it appears probable, however, that the crest at 7:06 was the second wave at Hilo, not the first. If so, allowing for the observed 15-minute interval between later waves, the first rise at Hilo probably started at about 6:45. Computed from these times of arrival, the approximate average speed of the tsunami from its origin to Honolulu and Hilo was, respectively, 490 and 498 miles an hour. On entering shallow water the waves decreased greatly in speed. The waves moving up Kawela Bay, on Oahu, were estimated by Shepard to be moving only about 15 miles an hour. Similar low speeds near shore were reported

by other observers, and are comparable to the speed of 20 miles an hour recorded in San Francisco Bay (C. K. Green, 1946, p. 492).

The interval between the first and third wave crests, as recorded on the Honolulu tide gage (fig. 2), was about 25 minutes, indicating an average interval between early wave crests of approximately 12.5 minutes. The interval between the first wave crest and the succeeding trough was 7.5 minutes, however, indicating a wave period of 15 minutes at the beginning of the disturbance. This corresponds with the mean wave period of 15.6 minutes found by Green (1946, p. 499) at Honolulu and eight other stations on the coasts of North and South America. At the mouth of Nuuanu Stream in Honolulu, C. K. Wentworth observed an interval of approximately 15 minutes between successive bores ascending the stream, and a wave period of about 15 minutes was observed by J. B. Cox and D. C. Cox at Waikiki at about 7:45 a. m. Observations elsewhere were poor, but in general indicated an interval not far from 15 minutes between the early waves of the series. The interval between later waves at Honolulu (fig. 2) and elsewhere was shorter and less regular, probably because of the arrival of chains of waves traveling by somewhat different routes, refracted around different sides of islands, and reflected at various points, as well as traveling by the most direct route. Probably contributing to the irregularity of later waves were wind waves and also the free-period oscillations, in harbors and channels, known as "seiches." If the period of the waves is assumed to be 15 minutes, and the average speed to be about 490 miles an hour, the average wave length from crest to crest was about 122 miles.

Direct observations on the height of the waves in the open sea are lacking, but theoretical considerations indicate that the height probably did not exceed 2 feet from crest to trough.⁴ If so, the small height combined with the very great wave length should have made the waves imperceptible to ships at sea. That such was indeed the case is indicated by the fact that the master of a ship lying offshore near Hilo could feel no unusual waves, although he could see the great waves breaking onshore. Crews of fishing boats in the Hawaiian area also reported no unusual conditions at the time of the tsunami, although heavy storm waves were running. The few reports of violent waves of great height from ships at sea were probably occasioned by storm waves, together with the knowledge that a tsunami was taking place.

The nature of the waves sweeping up onto Hawaiian shores varied greatly from place to place. At some places the water rose gently,

⁴ Based on the assumption of a 10-foot wave in 10 feet of water, and the variation of the wave height inversely as the fourth root of the depth.

flooding over the coastal lands without the development of any steep wave front. At such places most of the damage resulted from the violent run-back of the water to the sea. At some localities, although the general water surface rose gently, ordinary storm waves moved in over the top of the broad swells of the tsunami, and there at least part of the damage was caused by the storm waves. At most places, however, the waves of the tsunami swept toward shore with steep fronts and great turbulence, causing a loud roaring and hissing noise. Locally, the wave closely resembled a tidal bore, the steep front rolling in over comparatively quiet water in front of it. Behind the steep front, the wave crest was broad and nearly flat, with smaller storm waves superimposed upon it. Such bores were best developed in bays and estuaries, but waves of closely similar form were observed crossing shallowly submerged reefs upon otherwise open coasts.

At many places the violence of the waves moving shoreward was sufficiently great to tear loose heads of coral and algae, up to 4 feet across, and toss them onto the beach as much as 15 feet above sea level. Locally, blocks of reef rock weighing several tons were quarried at the outer edge of the reef and thrown onto the reef surface.

Between crests, the water withdrew from shore, exposing reefs, coastal mud flats, and harbor bottoms for distances up to 500 feet or more from the normal strand line. The outflow of the water was rapid and turbulent, making a loud hissing, roaring, and rattling noise. At several places houses were carried out to sea, and in some areas even large rocks and blocks of concrete were carried out onto the reefs. Sand beaches were strongly eroded by the outgoing water. People and their belongings were swept to sea, some being rescued hours later by boats and life rafts dropped from planes.

At a few places, generally but not exclusively on the sides of the islands away from the wave origin, the first wave was reported to have been the highest. At those places, the rise was generally of the quiet sort. There are, however, no instrumental records showing the first wave to have been the highest, and it is possible that at places reporting the first wave as the highest, earlier waves may have been overlooked. Much more generally the third or fourth wave was reported to have been the highest and most violent. The third crest was the largest at the Honolulu tide gage (fig. 2). At other localities the sixth, seventh, or eighth waves were said to have been the highest. At Waimea River, Kauai, the sixth crest was higher than any other, both in absolute level and in its height above the preceding and succeeding troughs.

In general, if not everywhere, the size and violence of the waves increased to a maximum with the third to eighth waves. The oscillations then gradually decreased in amplitude over a period of at least

2 days, but with occasional waves which were larger than those just before and after them. Such temporary increases in wave height probably resulted from mutual reinforcement by the essentially simultaneous arrival, in phase, of waves which had traveled different paths, or from the coincidence of tsunami waves with storm waves or seiche oscillations.

Measures of the height of the waves approaching shore in shallow water, but before they dashed up on shore, are poor. At Kawela Bay, Oahu, Shepard estimated the height of the waves advancing across the reef to have been as much as 18 feet, and observers estimated the height of the waves crossing the reef off Lanikai, on Oahu, to have been about 7 feet. Photographs taken at Hilo show the top of the breakers to have been 25 feet above the normal bay surface where they struck Cocoanut Island, but the waves may have increased considerably in height in crossing the breakwater, and the effect of dashing up on the shore was probably already present, further exaggerating the height. Photographs of some of the late waves at the mouth of the Wailuku River, in Hilo, show them to have been 6 to 8 feet high (pl. 6), and early waves undoubtedly were higher. In general, these heights correspond fairly closely with the measured heights to which the water dashed on the shore at those localities. At any rate it appears clear that the waves not only slowed down, but increased in height on entering shallow water. George Green (1838) states that the wave height varies inversely as the fourth root of the depth of the water.

Most observers reported the first movement on Hawaiian shores to have been a withdrawal of the water. However, the only available instrumental records, at Honolulu and Waimea, both indicate the first movement to have been a rise. The instrumental records are probably more reliable than the reports of untrained observers. The initial rise at Honolulu was small (fig. 2), and a similar small rise at other localities may easily have been overlooked. Certainly it would have been less impressive than the large withdrawal of the water from shore as the succeeding trough approached. It is interesting to note that the records of tide gages along the coasts of North and South America obtained by C. K. Green (1946, p. 497) all show the initial movement to have been a rise, with amplitude of about one-third that of the ensuing trough.

HEIGHTS REACHED BY WAVES ON HAWAIIAN SHORES

Measurements of high-water marks have been made around the shores of all five major islands of the Hawaiian group. The measured heights are shown on figures 3 to 7. All heights are stated in feet above lower low water. At each point sea level was estimated, the height of the high-water mark above that level was measured by means of hand level or steel tape, and the measurement reduced by

means of tide tables to height above lower low water. Some inaccuracy undoubtedly has entered in the estimation of mean sea level, but it is believed that the heights are probably accurate to within 1 foot. The levels measured include: points indicated by eyewitnesses as the upper limit of the water, lines of flotsam or swash marks, the upper limits of soil and vegetation scouring, levels of consistent scratching and barking on trees, and the upper level of staining on the walls of buildings.

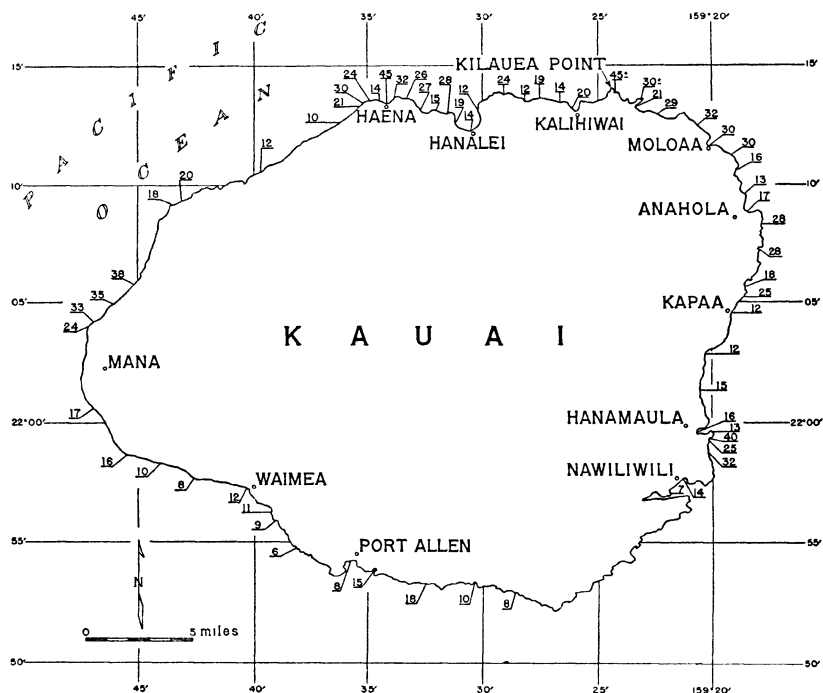


FIGURE 3.—Map of the island of Kauai, showing heights reached by the water during the tsunami of April 1, 1946. Heights are in feet above lower low water.

The measured heights of high-water marks range from 55 feet at Pololu Valley on Hawaii, 54 feet at Waikolu Valley on Molokai, and 45 feet at Haena and Kilauea Point on Kauai, to 2 feet at Kaunakakai on Molokai, 2 feet at Milolii and Hoopuloa on Hawaii, and less than 2 feet at the head of Kaneohe Bay on Oahu. Causes of the variations in height will be discussed in a later section.

Most of the heights measured are, of course, not the heights of the actual waves, but rather the heights to which the water was driven on shore. On a vertical cliff directly across the path of the wave, this height may theoretically amount to twice the height of the actual wave. On slopes less than vertical, or on cliffs at an angle to the

direction of wave advance, it should be somewhat less than twice the wave height. This measure represents the height of dash of solid water, but very abundant spray may be thrown much higher. Moreover, storm waves riding on the crest of the broader swells of the tsunami undoubtedly added in places to the height to which water dashed on shore. There are places where normal trade-wind waves are flung to a height nearly as great as that reached by the tsunami, and many places, particularly on shores facing away from the origin

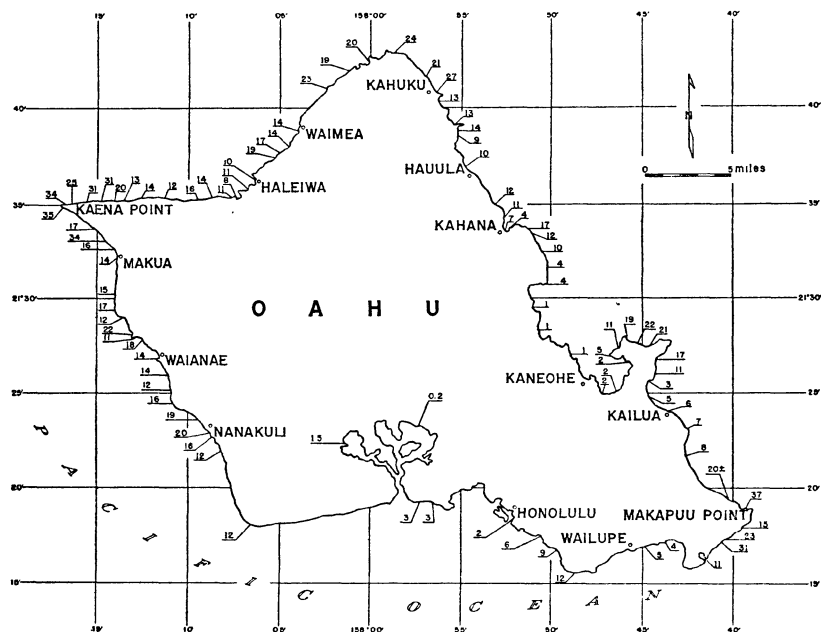


FIGURE 4.—Map of the island of Oahu, showing the heights reached by the water during the tsunami of April 1, 1946. Heights are in feet above lower low water.

of the tsunami, where waves of heavy storms reached appreciably higher than did the waves of the tsunami.

It is not possible to make reliable estimates of the magnitudes of these complicating factors, as there are too many unknown elements involved. However, it is probable that most of the water heights recorded for the tsunami on the northern and eastern sides of the islands were appreciably increased by these factors.

FACTORS INFLUENCING THE HEIGHTS AND INTENSITIES OF THE WAVES

It may be assumed that the size and speed of the waves approaching the islands from the open ocean to the north were essentially the same throughout the length of the Hawaiian Archipelago. Differences in

height reached by the water and in violence of wave attack along Hawaiian shores must be attributed to local influences modifying the size and behavior of the waves.

The factors found to have affected the height and intensity of the waves during the tsunami of April 1, 1946, are:

1. Orientation of the coast line with respect to the point of origin of the tsunami.
2. Shape of the island.
3. Exposure to storm waves.
4. Submarine topography.
5. Presence or absence of reefs.
6. Configuration of the coast line.
7. Merging of waves from different directions, or of different types.

Orientation of the coast line with respect to the point of origin of the tsunami.—In general, the heights reached by the water were greatest on the sides of the islands facing the origin of the waves, and lowest on the sides away from the wave origin. This is evident from even a cursory inspection of the maps (figs. 3 to 7). Heights average consistently greater on the northern than on the southern sides of the islands. All the extreme heights were measured on the northern or northeastern sides. Conversely, most of the lowest figures were found on the southern and southwestern sides. It appears almost self-evident that this should be so. Waves striking northern shores retain their full force, whereas the refracted waves striking southern shores suffer a diminution in force and height. This effect is discussed for wind waves in Breakers and Surf (U. S. Navy Hydrographic Office, 1944, pp. 12-13). No wave can be refracted or reflected without losing some of its force.

Shape of the island.—Waves were refracted around circular or nearly circular islands much more effectively than around angular or elongate islands. This fact had a marked effect on the height and violence of waves on the southern shores. Thus the water reached considerably greater heights along the southern coast of the nearly round island of Kauai (fig. 3) than along the southern coast of the angular and elongate island of Molokai (fig. 5), even though the heights along the northern coast of Molokai were on the average perhaps a little greater than those on the northern coast of Kauai. The contrast between the very high average height on the northern coast of Molokai and the very low average height on the southern coast is greater than that between the two sides of any other island, although the difference between the extreme highs and lows is almost exactly the same as on the island of Hawaii (fig. 7).

Exposure to storm waves.—At the time of the tsunami, large storm waves had been running for several days. As already pointed out, these storm waves riding in on the backs of the broad swells of the

tsunami in places undoubtedly increased the height to which the water dashed on shore. Moreover, in other places, where the rise in water level due to the tsunami was gentle, storm waves on top of the tsunami were responsible for much of the damage. The generally greater violence of the waves on the windward (northern and northeastern) coasts as compared to that on the leeward coasts may have been in considerable part the result of the large storm waves which were driving in on the windward coasts. Places on the windward coasts which were sheltered from the storm waves also experienced less violent waves. Thus at Kalaupapa, on the sheltered side of the peninsula on the windward side of Molokai, both photographs and the testimony of observers indicate that the rise of 25 feet caused by the tsunami was not violent. On the windward coasts, much of the rapid variation in

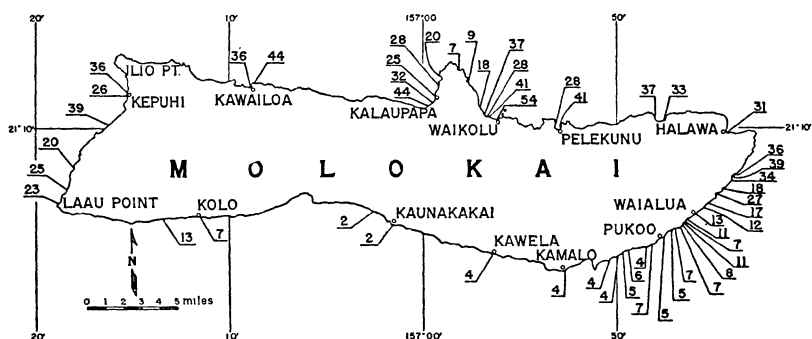


FIGURE 5.—Map of the island of Molokai, showing heights (in feet above lower low water) reached by the water during the tsunami of April 1, 1946.

intensity of wave attack may have resulted from the caprice of storm waves.

Submarine topography.—Owing to their great wave length, the waves were somewhat affected by the ocean bottom throughout their course. However, the effect of the bottom increased greatly as the waves moved into shallow water, and caused a slowing of the wave, an increase in its height, and a steepening of its front. A direct evidence of the increase in height of the waves in shallow water was afforded by the lesser heights reached by the water at the ends of certain peninsulas projecting into deep water and not prolonged seaward by pronounced ridges, as compared with the heights on adjacent shores rising from shoal water. Thus at the end of Kalaupapa Peninsula, on the northern coast of Molokai (fig. 5), the water dashed only 7 feet above normal sea level, distinctly less than do the waves of ordinary storms; whereas on the coasts rising from shoal water both east and west of the peninsula, the water swept up to heights of 30 to 54 feet. At the end of Keanae Peninsula, on the northern coast of Maui (fig. 6),

the tsunami reached heights only a little greater than large trade-wind waves.

Submarine ridges and valleys, particularly those pointing toward the wave source, were of great importance in their effect on the strength of the waves. The best examples of the effect of ridges are found on the northern coast of Kauai. A long ridge extends in a direction slightly west of north from Haena, to a depth of about 8,000 feet (fig. 9). Another extends northeastward from Kilauea Point, to even greater depths. The greatest heights (45 feet) reached by the water on the shores of Kauai were at the heads of these two ridges (fig. 3).

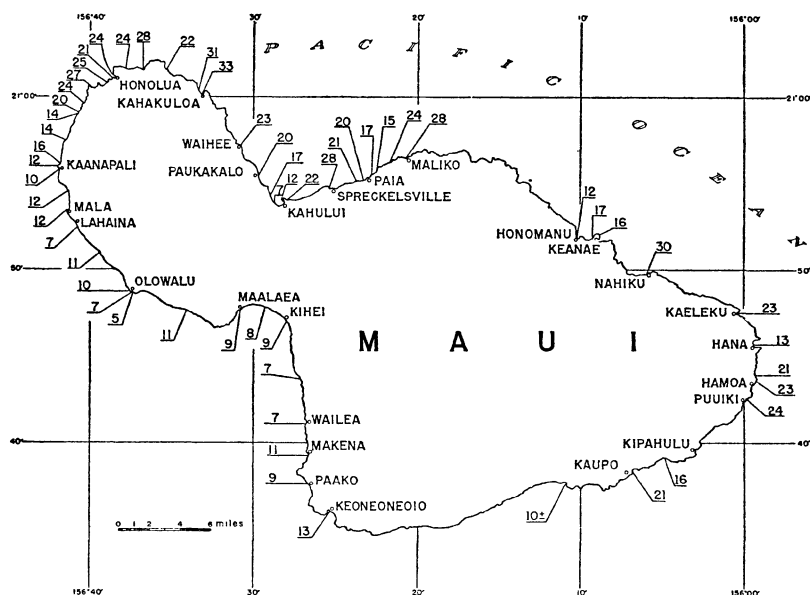


FIGURE 6.—Map of the island of Maui, showing heights (in feet above lower low water) reached by the water during the tsunami of April 1, 1946.

Another ridge extending northwestward from the western coast of Kauai is probably responsible for heights of 35 to 38 feet at its head. Long ridges projecting from Kaena and Kahuku Points on Oahu similarly caused an increase in wave heights there as compared to the heights on both sides (fig. 4). The ridges projecting eastward north of Hilo Bay and at Cape Kumukahi on Hawaii had, on the other hand, no such pronounced effect on the heights at their heads; but it should be noted that they extend across the general direction of wave advance, not toward it.

The greater heights reached by the water at the heads of submarine ridges are not difficult to explain. The ridge has a greater effect in limiting the movement of water particles in the advancing

wave than does the deeper water alongside it. Consequently the portion of the wave over the ridge is retarded more than that away from the ridge, and the wave front becomes bent, with its concavity directed toward the ridge head. The result is a focusing of wave force on the shore at the head of the ridge (U. S. Navy Hydrographic Office, 1944, p. 13).

Similarly, in moving toward shore along the axis of a submarine valley, the part of the wave in the deep water along the valley axis moves faster than that in shallower water on the two sides. In consequence the wave front becomes bent, with its convexity toward the valley head. In the vicinity of the valley head the force lines (orthogonals) of the wave are diffused or spread apart, and over any unit area the force of the waves striking shore is greatly decreased.

An example of the effect of a submarine valley in lessening the force of the waves at its head is found at Kahana Bay, on Oahu (fig. 4). There the waves dashed to heights of 11 to 17 feet on the coasts north and south of the bay, but reached heights of only 4 to 7 feet in the bay itself. A small submarine valley extends 2 miles northeastward from the bay, to a depth of 150 feet. An example on a much larger scale is afforded by the zone of small heights along the northwestern shore of Kauai (fig. 3), at the head of a broad swale extending outward to oceanic depths. The broad valleylike depression off the eastern coast of Hawaii south of Hilo Bay probably also was somewhat effective in reducing the heights reached by the water along that coast. Although fairly great, ranging from 16 to 19 feet, the heights there are not much greater than those reached by ordinary storm waves.

Presence or absence of reefs.—The presence of a well-developed fringing reef appears to have had a decided effect in reducing the intensity of wave onslaught. Along the reef-protected northern coast of Oahu the heights reached on shore by the waves were on the average decidedly less than on the unprotected northern coasts of Molokai and Hawaii, or on the less-protected northern coast of Kauai. The best-developed coral reef in the Hawaiian Islands fills Kaneohe Bay on Oahu, where it has a width of about 3 miles. Despite the fact that the broad mouth of Kaneohe Bay is open to the north and northeast, the tsunami produced a rise in water level at the bay head which was so small as to be hardly perceptible to observers, and, so far as could be determined, nowhere exceeded 2 feet. Along the shore north of the bay the heights ranged from 4 to 10 feet, and on the end of Makapuu Peninsula southeast of the bay the heights reached more than 20 feet (fig. 4).

The lesser heights along the southern shore of Molokai were probably partly due to the wide protecting reef. The effect of the reef in reducing wave violence along that shore is well shown at places

where channels cross the reef. There the waves striking the shore at the heads of the channels were distinctly larger than those reaching shore on each side of the channel. Thus at the head of a small channel which crosses the reef just west of the mouth of Kainalu Stream the water rose 11 feet, damaging houses, whereas just east and west of this channel the water rose only 7 to 8 feet.

Configuration of the coast line.—It is generally considered that the effects of tsunamis should be intensified near the heads of V-shaped embayments. Such embayments greatly increase tidal fluctuations, as in the Bay of Fundy, and might be expected to act likewise on the similarly long waves of a tsunami. Imamura (1937, pp. 125-127) states that as such a wave rolls up a V-shaped embayment its height increases in inverse ratio to the width and depth of the bay, and cites examples of such increases in height of the waves toward the bay head during Japanese tsunamis. Consequently, special search was made for this phenomenon in funnel-shaped bays on Hawaiian shores. No good examples could be found. Hilo Bay would appear to be an almost ideal site for such funneling, but measurements around its shores show no systematic increase in heights toward its head (fig. 7 and 8). Similarly there was a lack of increase in heights toward the head of the broad V-shaped embayment on the northern coast of Maui. Possibly the extreme height of 54 feet at Waikolu Valley, on the northern shore of Molokai, may have been partly the result of funneling between Kalaupapa Peninsula and the point and small islands just east of the mouth of the valley. At both Pololu Valley on Hawaii and Pelekunu Valley on Molokai, the water level was higher at the bay head than on the walls of the bay part way out. However, at Pololu Valley, and probably also at Pelekunu, this level was the result of a local upsurge where the waves crossed the beach. Conversely, several bays were found in which the heights reached by the water were less at the bay head than near its mouth.

Several small steep valleys, debouching into small bays, were found in which the water rose to appreciably greater heights along the valley axis than on the sides near the bay mouth or opposite the beach. Thus, in the small bay just south of Hanamaula Bay, on the eastern shore of Kauai, the water rose only 25 feet on the bay sides, but swept up the small valley at its head to a height of 40 feet. At Moloaa, on Kauai, the water reached an altitude of 40 feet in the axis of the valley, but only 30 to 35 feet on the bay walls. Again, at Honouliwai, on Molokai, the water reached a height of 27 feet opposite the beach, but went 6 feet higher up the valley. These are merely specialized examples of effect, upon the rush of water up on shore, of a topography above sea level which served to concentrate the intrushing water.

Merging of waves from different directions.—Wave crests traveling by different routes may arrive at a given locality simultaneously

giving rise to a wave of greater size than either. Likewise, the simultaneous arrival by different routes of a wave crest and a wave trough may effectually cancel out both. Thus, variations in the size and intensity of waves, particularly on the sides of the islands away from the wave origin, may result from the arrival, either in or out of phase, of

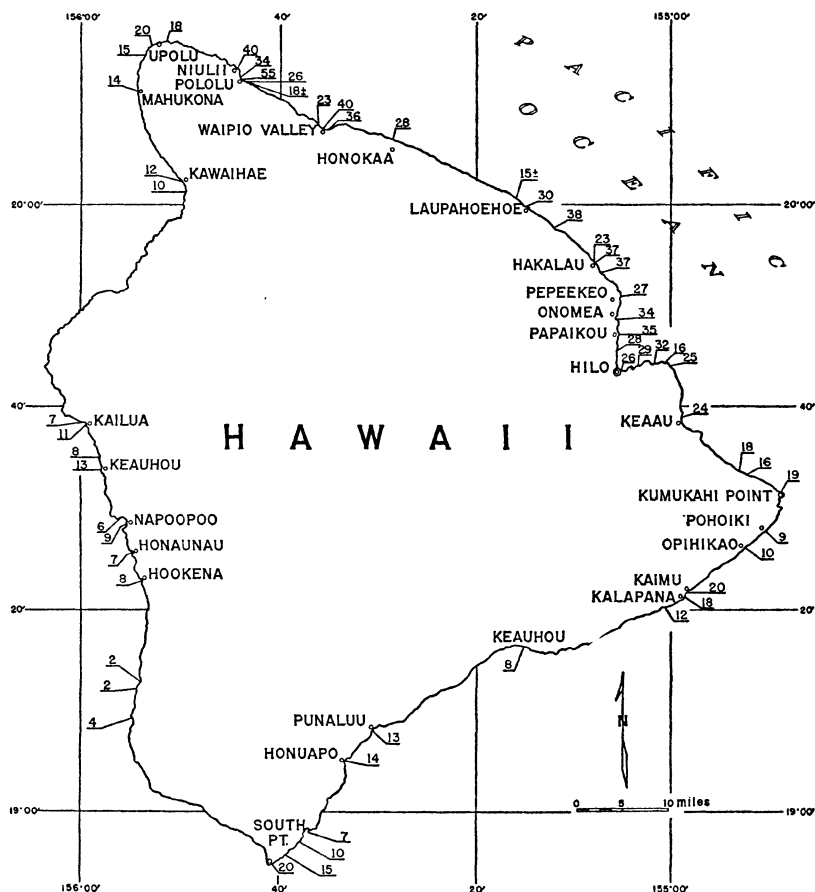


FIGURE 7.—Map of the island of Hawaii, showing heights (in feet above lower low water) reached by the water during the tsunami of April 1, 1946.

two wave trains. During the tsunami of 1946 several examples of the formation of a large wave by the juncture of two smaller ones were observed. Thus, in the Keaukaha area east of Hilo, witnesses described the arrival of a wave from the north simultaneously with one from the northeast, which built up a very high crest at the place of juncture. At the head of Maunalua Bay, on the southeastern shore of Oahu, two waves were seen to advance up channels across the wide reef, move toward each other parallel with the shore, and meet, throwing water

upward like the spray from a geyser. The water dashed up on shore to a height of only 3 feet except at the place of juncture, where it swept over the top of a sandspit 5 feet above sea level.

Progressively southward around the shores of Kauai, the average height of the high-water marks gradually decreases, and along much of the southern shore it is 6 to 12 feet above sea level. However, in a zone 3 or 4 miles wide it ranges from 15 to 18 feet. This zone is almost directly across the island from the direction of wave origin, and probably represents the area in which the waves refracted around opposite sides of the island met and reinforced each other.

DAMAGE BY THE TSUNAMI

Damage by the tsunami can be divided into structural damage, damage by erosion and deposition, and damage by flooding. The total property damage has been estimated by the office of the Governor, Territory of Hawaii, at about \$25,000,000. Space permits only a brief review of the types of damage. The numbers of dwellings destroyed and damaged by the tsunami on the major islands are listed in table 2 on page 276.

Structural damage includes damage to buildings, roads, railroads, bridges, piers, breakwaters, fishpond walls, and ships. Frame buildings at low altitudes along Hawaiian shores suffered extensive damage. Some were knocked over, by the force of the waves, by cutting away of the sand on which they stood, or by destruction of the foundations. Others were bodily washed away from their foundations. Some had walls pushed in by the force of the water, and in a few residences the water went on through the house and took out the opposite wall. As with earthquakes, there was a tendency to reduce the few two-story buildings to a single story, by destruction of the lower story. It is noteworthy that houses which were well built and tied together internally could be moved for considerable distances without suffering severe damage. Even more striking was the fact that houses elevated on stilts a foot to several feet above the ground survived the waves much more effectively than did those built directly on the ground. Apparently the water was able to pass under such houses without greatly disturbing them, unless it was deep enough actually to float the house off the stilts. The few reinforced concrete structures in devastated areas suffered little or no damage except that caused by flooding.

The railroads along the northern coast of Oahu and in Hilo were wrecked, partly through destruction of the roadbed, but largely because the tracks were shifted off the roadbed, either inland or shoreward. Locally rails were torn loose, but more generally the track was moved en masse, a motion probably aided by the buoyancy of the ties. Coastal highways also were partly destroyed, largely by undercutting as the water returned seaward, but partly by the direct force of the waves.

Several highway and railway bridges were destroyed. Most appear to have been partly or entirely lifted from their foundations by the rising of the water under them. The head of the pier at Waianae, Oahu, was damaged in the same manner. At the Wailuku River, in Hilo, an entire span of the steel railroad bridge was torn loose and carried 750 feet upstream, passing under but not damaging a highway bridge. At Kolehale Stream, 11 miles farther north, an entire leg of the high steel railroad trestle was removed and carried upstream about 500 feet.

Part of the end and much of the shed of pier 1 in Hilo was wrecked by the force of the wave. Most of the damage on pier 2, however, resulted when heavy pontoons, which had been moored nearby, were washed across the pier. The wharves at Kahului on Maui were flooded, but sustained little structural damage.

The upper part of the breakwater at Hilo was about 61 percent destroyed (fig. 8). Blocks of rock weighing more than 8 tons were lifted off the breakwater and dropped both inside and outside it. Destruction was limited, however, to the part above water or that only slightly submerged. The average depth of water over the destroyed sections after the wave was only about 3 feet. The breakwater at Kahului, Maui, also suffered minor damage. At both Hilo and Kahului the breakwaters appear to have reduced materially the height and violence of the waves in the enclosed portions of the harbors.

Many small boats were washed ashore and damaged. Railroad cars were overturned on Oahu, Maui, and Hawaii. Many automobiles were wrecked. The loose stone walls of fishponds along the southern coast of Molokai were partly thrown down. The mill of the Hakalau Sugar Co., situated only about 10 feet above sea level at the mouth of Hakalau Gulch on the island of Hawaii, suffered severe damage.

Erosion by the tsunami resulted in the partial removal of some sand beaches, in some places causing a retreat of the shore line for several tens of feet, cutting of small scarps, and forming of large beach cusps at the heads of beaches; locally, erosion caused stripping away of a small amount of soil. The erosion was largely concentrated high on the beach, several feet above sea level. Some of the sand from the beaches was carried inland and redeposited. At Haena, Kauai, the highway was buried under 4 feet of sand, and thinner layers of sand covered roads on Oahu.

Flooding caused much water damage to house furnishings and personal property.

LOSS OF LIFE AND PERSONAL INJURY

The following table summarizes, by islands, the number of persons killed, injured, or missing as a result of the tsunami. The figures were supplied by the American Red Cross. Most of the deaths were by drowning. By far the heaviest toll was at Hilo, with 83 known dead

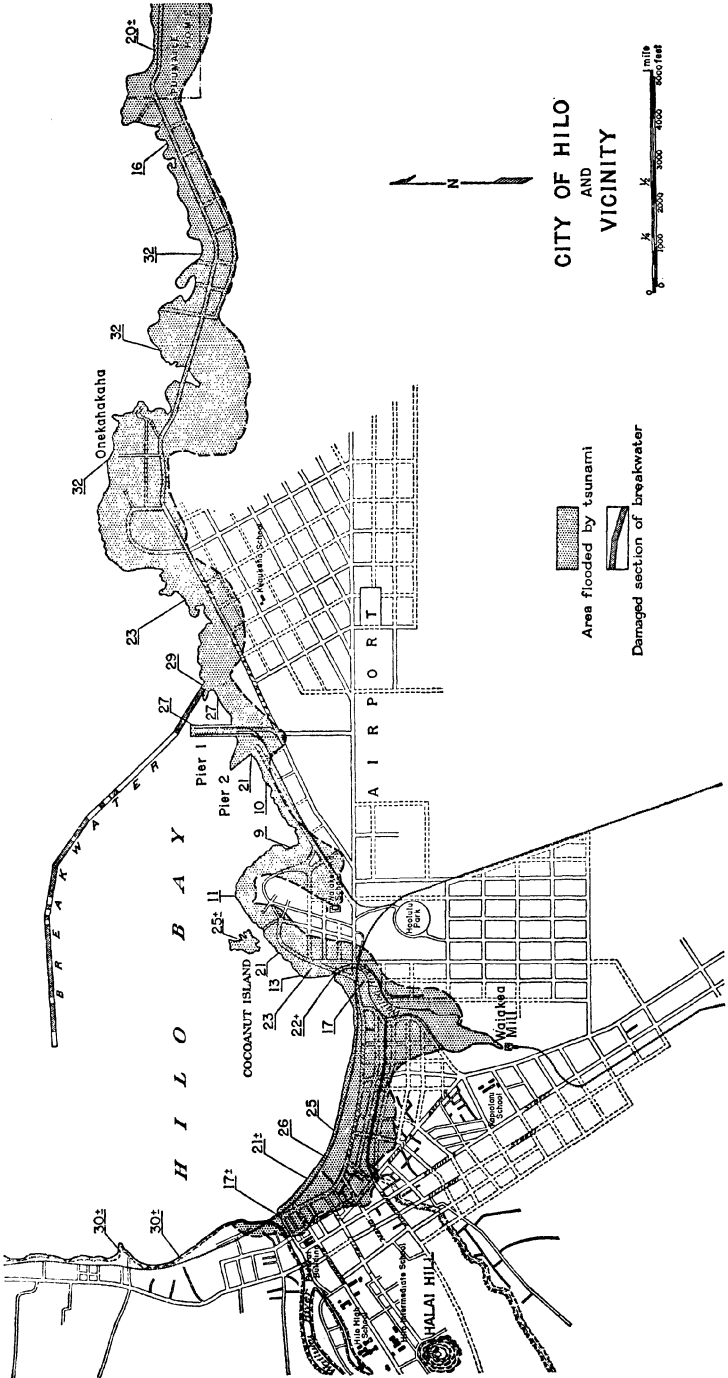


FIGURE 8.—Map of the Hilo area on the island of Hawaii, showing the heights reached by the water, the area of flooding, and the portion of the breakwater destroyed (shaded portions) during the tsunami of April 1, 1946. Heights are in feet above lower low water.

and 13 missing. Those listed as missing have been missing for more than 2 months, and must be presumed dead, bringing the total number of probable dead to 159. Great as it was, this loss of life was moderate compared to that in some other tsunamis, such as that of 1896 in the Sanriku district in Japan, which took more than 27,000 lives (Byerly, 1942, p. 72).

TABLE 2.—*List of casualties during the tsunami of April 1, 1946*

Island	Known dead	Missing	Injured ¹	Homes demolished ²	Homes damaged ²
Hawaii.....	87	34	153	283	313
MauI.....	9	5	2	65	144
Oahu.....	9	0	0	67	335
Molokai.....	0	0	0	13	14
Kauai.....	10	5	8	60	130
Total.....	115	44	163	488	936
	159				

¹ Injury sufficiently serious to require hospitalization.

² Homes only; other buildings not included. Data from Lewers & Cooke, Ltd.

MITIGATION OF DISASTERS RESULTING FROM FUTURE TSUNAMIS

There is no Hawaiian shore which is exempt from tsunamis. The most likely sources of devastating tsunamis are the North Pacific and South America. The areas heavily hit by the 1946 tsunami are probably those most likely to be hit hard again by tsunamis from the North Pacific. Violent tsunamis from Central or South America might, however, cause much more damage than did the 1946 tsunami along eastern and southern coasts. There is also possibility of serious damage on western shores by a tsunami from Japan, particularly if the tsunami occurred during a heavy southwesterly storm. Tsunamis of local origin might do heavy damage on any shore.

It is obviously impractical to consider the removal of all dwellings from Hawaiian shores because of the danger from tsunamis. It might, however, be advisable to prevent or restrict building in certain areas of greatest danger, particularly in centers of heavy population, such as the waterfront at Hilo. Construction of suitable sea walls might also be advisable in places. Sea walls cannot, however, be built high and strong enough to hold the water back completely, and an open zone should be left back of the wall in which the water pouring over the wall can use up its energy in turbulence. Any construction permitted in such areas should be of a wave-resistant type, such as reinforced concrete. These wave-resistant buildings would have the added virtue of serving as a line of defense for frailer structures behind them. Frame structures in rural areas should be built up off the ground, and far enough back from the edge of the beach to reduce the danger of undercutting. They should also be properly reinforced and tied together.

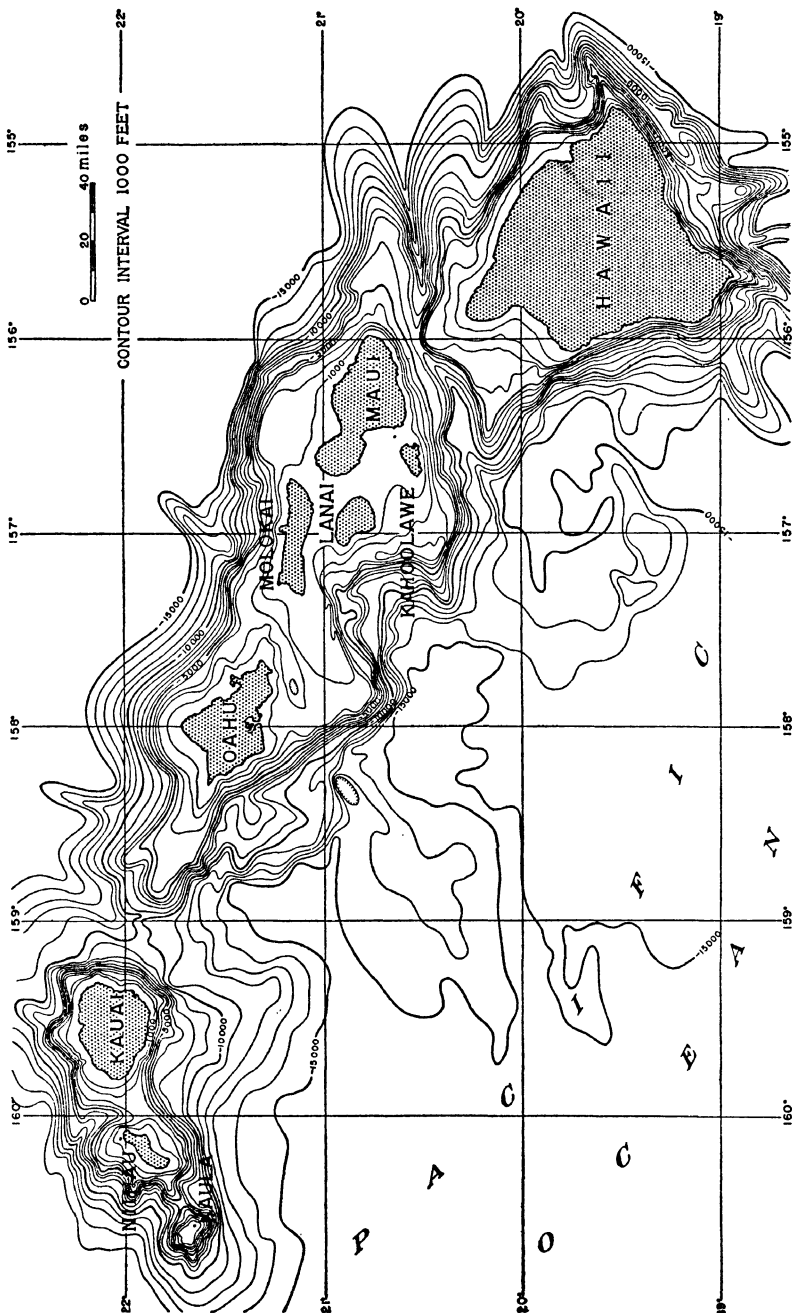


FIGURE 9.—Map of the Hawaiian Islands, showing submarine topography (after H. T. Stearns).

It appears inevitable that future tsunamis will cause loss of property on Hawaiian shores, but loss of life from all except tsunamis of local origin could be largely or entirely avoided. A system of stations could be established around the shores of the Pacific and on mid-Pacific islands, which would observe either visually or instrumentally the arrival of large long waves of the periods characterizing tsunamis. The arrival of these waves should be reported immediately to a central station, whose duty it would be to correlate the reports and issue warnings to places in the path of the waves. It should be possible in this way to give the people of the Hawaiian Islands enough warning of the approach of a tsunami to permit them to reach places of safety. The effectiveness of the warning, however, would depend on education of the public on the necessity for leaving areas of danger, and on the efficiency of the local organization in spreading the warning and evacuating the threatened areas. Eventually it should also be possible to state, at the same time, which areas are likely to suffer the most damage. Before that can be done, however, we need more knowledge of the behavior of tsunamis on Hawaiian shores, particularly tsunamis from sources in the eastern and western Pacific, and a more complete picture of the submarine topography around the Hawaiian Islands.

SUMMARY

The tsunami which reached the shores of the Hawaiian Islands on April 1, 1946, was the most destructive in the history of the Islands. Generated by a sudden shifting of the sea bottom on the northern slope of the Aleutian trough, the waves traveled southward to Hawaii with an average speed of 490 miles an hour, an average wave length of about 122 miles, and a height over the deep ocean of about 2 feet. Effects on Hawaiian shores varied greatly. Locally the water dashed more than 50 feet above sea level and swept as much as half a mile inland. Elsewhere the rise in water level was very small, and waves were gentle. Property damage was heavy but loss of life was moderate.

The heights and intensities of the waves at different points were influenced by position on the island toward or away from the source of the waves, offshore submarine topography, presence or absence of coral reefs, shore-line configuration, mutual reinforcement or interference by waves traveling different paths, and the presence or absence of storm waves. Loss of property during future tsunamis can be reduced by proper construction, by erection of sea walls, and by restricting or prohibiting construction in certain especially dangerous areas. Loss of life can be nearly or entirely eliminated by the establishment of a suitable system for warning of the approach of waves.

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1. WRECKAGE LEFT BY THE TSUNAMI ALONG KAMEHAMEHA AVENUE, HILO
Buildings on the left-hand (seaward) side of the street have been pushed into the street, some more or less intact, others as heaps of debris. Photograph by Francis Lyman.



2. HOUSE IN KEAUKAHA, EAST OF HILO, CARRIED INLAND ABOUT 100 FEET BY THE WAVES

The house in the background was above the reach of the water. Photograph by G. A. Macdonald.



1. MOUTH OF THE WAILUKU RIVER AT HILO, SHOWING THE ADVANCE OF ONE OF THE LATER WAVES INTO THE RIVER MOUTH

Photograph taken near the trough between two waves, showing very low water, and the waves starting up the river as the next crest approaches. The steel span from the distant railroad bridge is visible in the middle distance. Photograph by Francis Lyman.



2. A MINUTE OR SO LATER, THE WAVES ARE SWEEPING TURBULENTLY UP THE RIVER

Photograph by Francis Lyman.



1. THE VERY HIGH STAGE OF THE WATER, IN WAILUKU RIVER AT HILO, REACHED 3 OR 4 MINUTES LATER THAN THE STAGE SHOWN IN PLATE 2, FIGURE 2

Photograph by Warren Flagg.



2. SCARP 5 FEET HIGH CUT BY THE TSUNAMI AT THE HEAD OF THE BEACH AT MOLOAA, KAUAI

The roots were exposed by removal of the enclosing soil. Photograph by G. A. Macdonald.



1. RAILROAD TRACK SWEEPED INLAND FROM ITS BED AT WAIALEE, OAHU

Photograph by U. S. Navy.



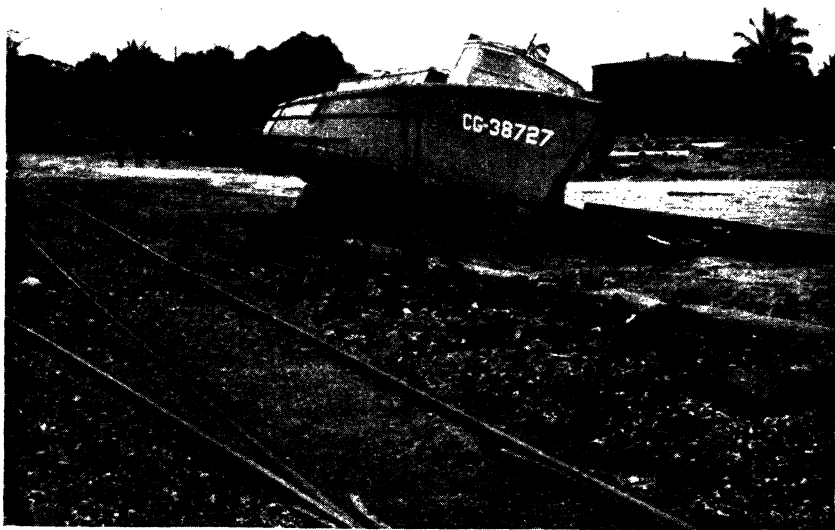
2. CORAL HEADS THROWN UP ON THE BEACH AT KAAAWA, OAHU, BY THE TSUNAMI

Photograph by G. A. Macdonald.



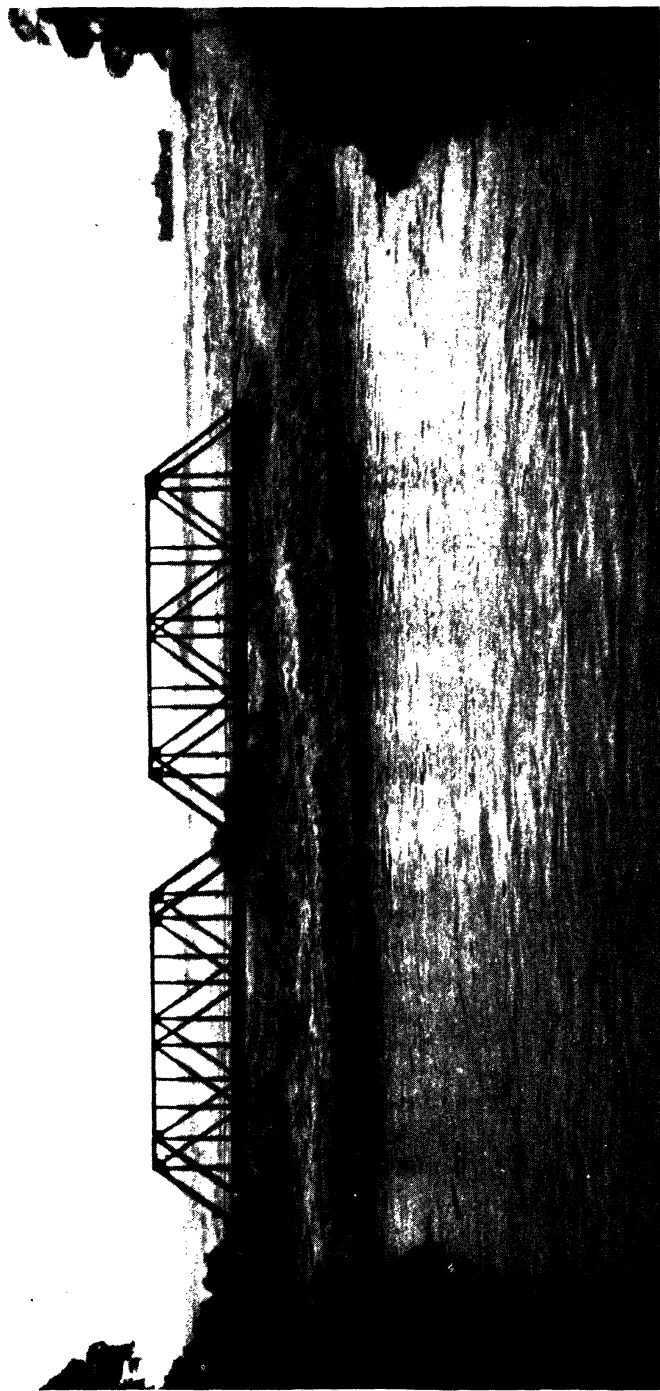
1. GROVE OF PANDANUS TREES PUSHED OVER, AND BLOCKS OF CORAL THROWN UP ON THE SHORE PLATFORM BY THE TSUNAMI NEAR HAENA, KAUAI

Photograph by F. P. Shepard.



2. SMALL BOAT WASHED INLAND AND LEFT STRANDED BY THE TSUNAMI NEAR PIER 1, HILO

Photograph by G. A. Macdonald.



BORE ADVANCING PAST THE RAILROAD BRIDGE AT THE MOUTH OF THE WAILUKU RIVER, HILO
Note the steep front, the turbulence of the water behind it, and the placidity of the water in front of it. Photograph by Shigeru Ushijima.

DROWNED ANCIENT ISLANDS OF THE PACIFIC BASIN¹

By H. H. Hess

Department of Geology, Princeton University

PART I. DESCRIPTION

A large number of curious, flat-topped peaks have been discovered scattered over millions of square miles in the Pacific basin. These peaks are roughly oval in plan and their slopes suggest volcanic cones. The remarkable feature about them is that they are truncated by a level surface which now stands approximately 750 fathoms (4,500 feet) below sea level. For convenience in discussing these submerged flat-topped peaks which rise from the normal ocean floor, the writer will henceforth call them "guyots" after the nineteenth-century geographer, Arnold Guyot.

Betz and Hess (1942) discussed the major features of the floor of the North Pacific. This was in the nature of a broad areal reconnaissance of the largest features of this extensive region. Since 1942, Hess has spent 2 years at sea in the western Pacific and has thus had the opportunity to fill in some details which bring to light many new relationships and necessitate some modification of ideas originally set forth. The data presented in this paper were obtained on random traverses incidental to wartime cruising on the U. S. S. *Cape Johnson*. What passed beneath the ship was recorded but it was not feasible to investigate further such interesting features as were encountered. Nevertheless it is evident that much information can be obtained on the geological history of an oceanic area by judicious use of available techniques. It is a vast and intriguing field for research under more auspicious peacetime conditions.

SCOPE OF PRESENT INVESTIGATION

From random sounding traverses across or merely grazing guyots an attempt will be made to construct a picture of their physical features. The data collected on the cruises of the *Cape Johnson* have

¹ Presented before the Section of Tectonophysics, American Geophysical Union, in Washington, D. C., on May 27, 1946. Reprinted by permission from American Journal of Science, vol. 244, November 1946, with added text and illustrations.

been supplemented by soundings obtained from the files of the Hydrographic Office, United States Navy. The origin and age of the flat upper surfaces of guyots represent the main problem of this paper. Secondly the relation of guyots to atolls of the northern Marshall Islands will be discussed.

AREAL DISTRIBUTION OF GUYOTS

The distribution of known and suspected guyots is shown in figure 1. Roughly they are known to occur north of the Carolines and east of

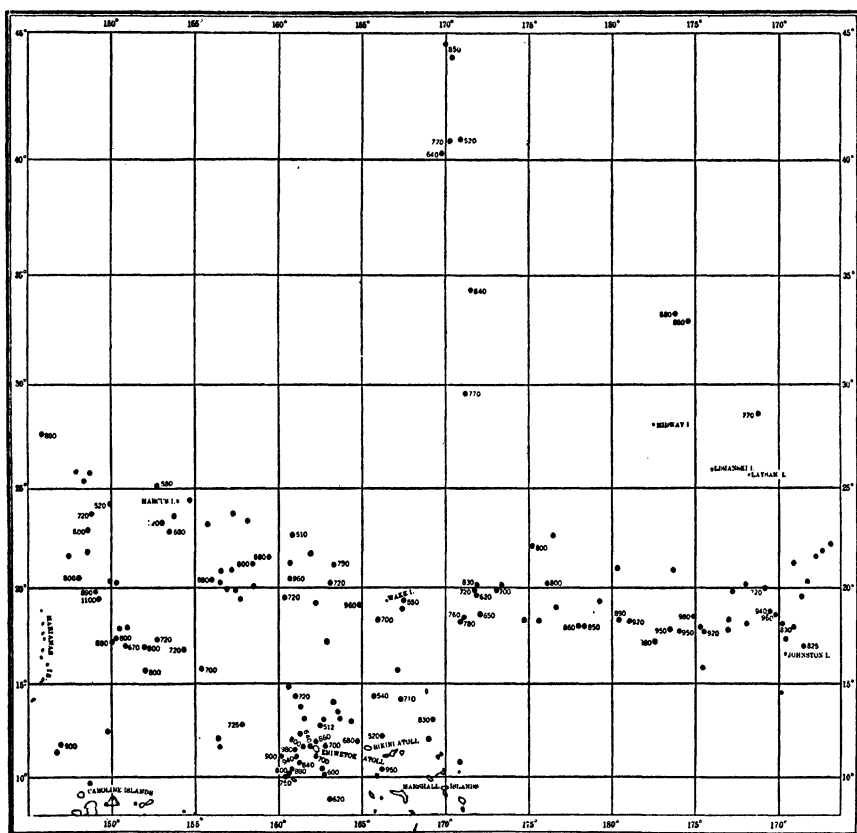


FIGURE 1.—Areal distribution of guyots in the western and central Pacific. The numerals next to some of the guyots indicate the depth in fathoms to the flat upper surface.

the Marianas and Volcano Islands between latitudes $8^{\circ}30'$ and 27° N. and longitudes 165° W. to 146° E. None has been found west and south of the above boundaries though this area has been at least as well explored as the former. North and east of the region outlined above it appears from scattered soundings that the area containing guyots

does extend to 45° N. to 165° W. Some of the seamounts in the Gulf of Alaska described by Murray (1941) almost certainly are guyots, whereas others appear to be of a different character. Twenty bona fide guyots were encountered at sea by the writer and some 140 more are indicated by soundings on Hydrographic Office charts and documents. Considering sparseness of deep-sea soundings in parts of the area mentioned above, it is likely that a large number of undiscovered ones are present.

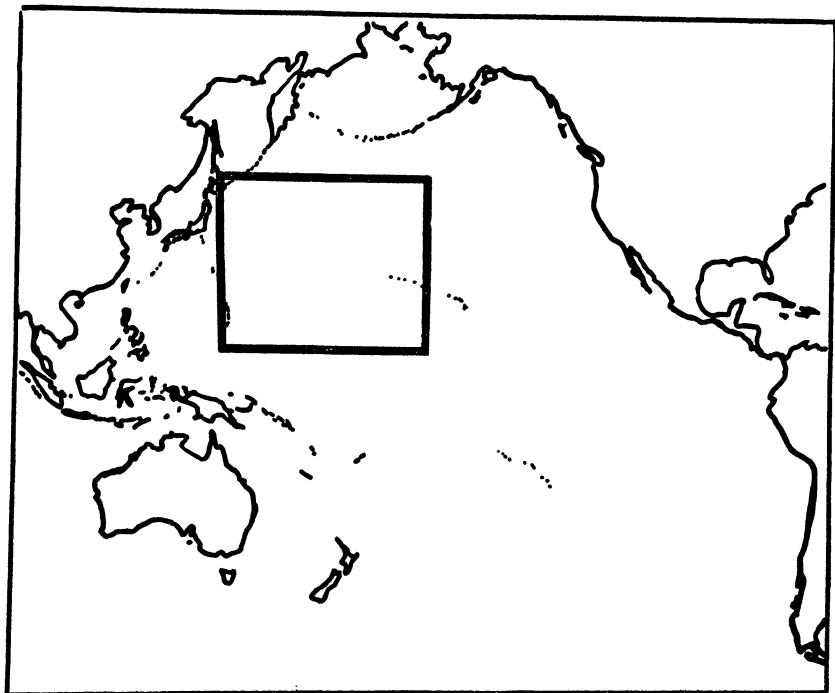


FIGURE 2.—Index map showing area included in figure 1.

PHYSICAL FEATURES OF GUYOTS

One of the best profiles obtained across a guyot was one encountered south of Eniwetok on October 6, 1944, in latitude $8^{\circ}50'$ N., longitude $163^{\circ}10'$ E. This guyot is about 35 miles in diameter at the base, and the truncated upper surface is about 9 miles in diameter. The top is remarkably flat at a depth of 620 fathoms.² The outer rim of the top is beveled by a gently sloping shelf 1 or 2 miles wide (slope 2° to 3°). The outer margin of the gentle slope is about 70 fathoms deeper than

² All soundings mentioned in this paper are uncorrected for salinity, temperature, and pressure, and were taken with fathometers set to a speed of sound in the sea water of 4,800 feet per second. The corrections would be too small to be of significance in this discussion.

the inner margin. This gentle slope breaks abruptly to 22° at its outer margin. The profile from the edge of the shelf to the normal ocean floor at 2,600 fathoms is, as might be expected, concave upward. From an average of 22° at the top it gradually decreases in steepness until it forms a smooth tangent with the ocean floor at the bottom.

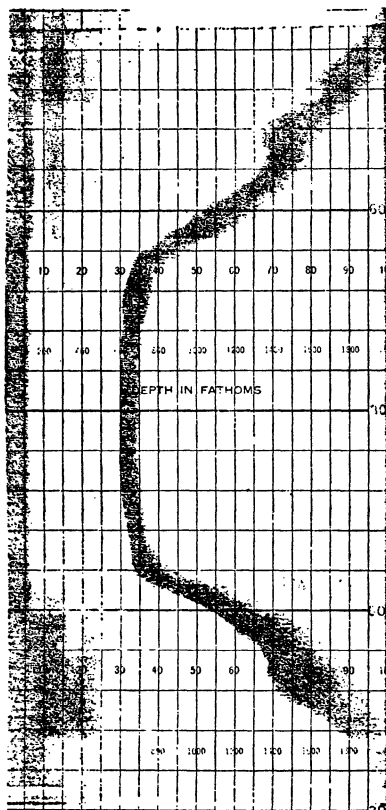


FIGURE 3.—Fathometer recorder trace of a typical guyot. Note irregularities on lower slopes with considerable thickening (lengthening) of the echo trace. These indicate steep slopes to the side (parallel to ship's course) and necessitate an adjustment to obtain the approximate depth immediately beneath the ship. The adjustment has been made in figure 4.

Figures 3 and 4 are reproductions of the sounding traverse across the guyot.

Guyots vary widely in size. One a few miles northeast of Eniwetok has a flat summit only a couple of miles across (latitude $11^\circ 45'$ N., longitude $162^\circ 55'$ E.); whereas one some distance farther northeast apparently has a flat upper surface 35 miles wide and has a diameter of 60 miles at its base (latitude 14° N., longitude $167^\circ 30'$ E.). In general they appear to be circular or oval in plan. No correlation has

been noted between the depths of the flat upper surfaces and the depths of the surrounding ocean floor, which normally ranges from 2,600 fathoms (15,600 feet) to 3,100 fathoms (18,600 feet). The observed depths of the flat upper surfaces of typical guyots range from 520 fathoms (3,120 feet) to 960 fathoms (5,760 feet), with most values concentrated near the center of this group (800 fathoms). Thus the guyots rise from 10,000 to 15,000 feet above the ocean floor. The flat tops of guyots in general do not exhibit accordance of summit levels. It is quite common to find groups of guyots in a relatively small area with flat tops varying several hundred fathoms from one

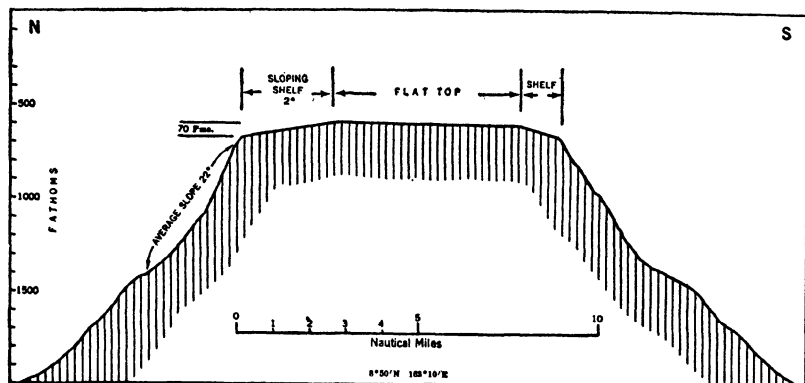


FIGURE 4.—This diagram was traced directly from figure 3 and adjustments for steep slopes to the side made. The vertical and horizontal scales and numerical values of the slopes in degree are given.

to another among the group. Less commonly two or three guyots in a group will have approximately the same depth.

A few guyots were found to have upper surfaces which were gently undulating rather than flat. These undulating or hummocky surfaces have a maximum relief of about 40 fathoms. In most cases the flat surface can be seen here and there in the profiles and it passes *beneath* the hummocky material (fig. 5). Judging from the evidence, most guyots have been swept clean of the fine sediments which must be continually settling upon them. In the case of the rare, hummocky ones it would appear that the fine precipitates had for some reason not been completely swept off. It is rather surprising that the normal guyots are swept clean since water currents at such depths as these are thought to be slight. One must look to occasional bottom stir-up by tsunami (Bucher, 1940), though possibly currents related to tides might be strong enough. Once the sediment on these isolated, flat-topped peaks is stirred up, very little of it would be expected to fall back on top of the guyot. It would be dispersed over the surrounding area.

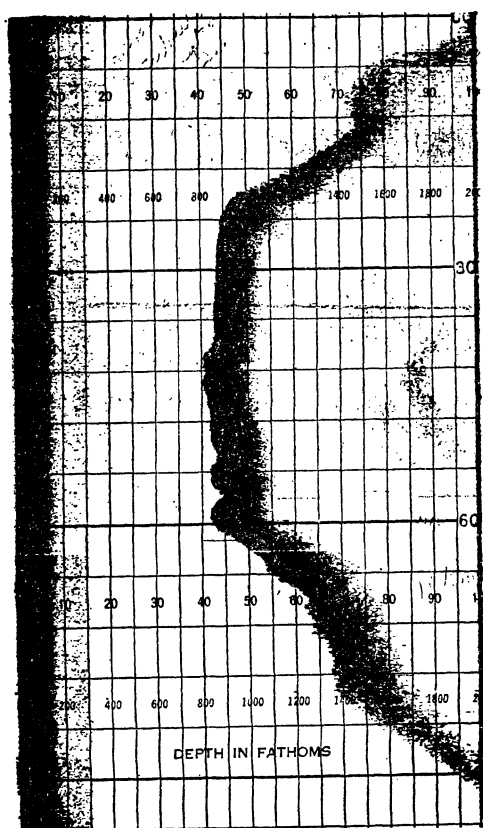


FIGURE 5.—Guyot showing hummocky type of upper surface.

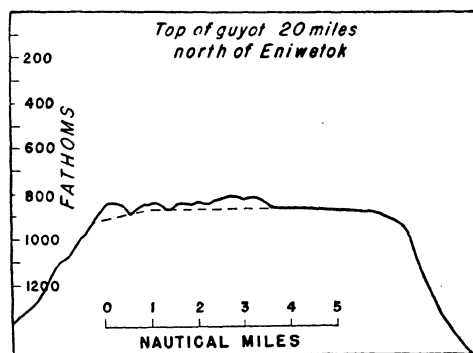


FIGURE 6.—Tracing of fathometer record shown in figure 5, adjusted and with scales indicated.

Though few guyots show any suggestion of terraces on their outer slopes, one large guyot near latitude 20° N., longitude 148° E. has a well-developed flat upper surface at 800 fathoms, and projecting from under its southeastern margin there appears to be a terrace or older guyot with a flat upper surface at 1,100 fathoms. In the area between Wake Island and Johnston Island there are a number of normal guyots rising from hilly areas which have numerous flat or nearly flat surfaces between 1,100 and 1,900 fathoms. These hilly areas with flat or nearly flat surfaces have as yet been insufficiently explored to understand the relationships they exhibit. They may represent areas of older, deeper guyots partly buried by sediments, but until a more detailed examination of them can be made, their nature will have to remain rather obscure. Such areas do not appear to be common

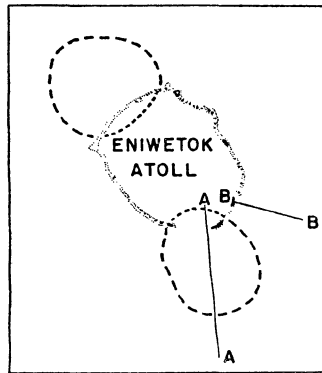


FIGURE 7.—Relation of Eniwetok Atoll to nearby guyots which are outlined on the diagram by dash lines.

elsewhere. Some of Murray's Gulf of Alaska seamounts possibly also fit into this category. The great majority of guyots rise from the normal ocean floor.

RELATION OF GUYOTS TO ATOLLS IN THE MARSHALL ISLANDS

Many guyots are present in close association with atolls in the northern Marshall Islands. The present discussion is centered about Eniwetok Atoll of that group. This atoll apparently rests in part upon two guyots so that the flat upper surfaces of the guyots project out beneath its southern and northwestern slopes resulting in a well-developed bench on those sides at a depth of 700 fathoms. The eastern side of Eniwetok shows a normal atoll slope with no suggestion of a bench, and the central portion of the western side shows similar features. Figure 7 shows the relationship between Eniwetok Atoll and the nearby guyots, and figures 8 and 9 show two profiles, one approaching the passage between Japtan and Parry Islands from the east and

the other approaching Wide Passage at the south end of the atoll from the south, which shows the guyot apparently disappearing beneath the atoll slope.

The absence of a 700-fathom bench locally around part of Eniwetok Atoll strongly suggests that the atoll and its volcanic core are younger than the benches which project from its southern and northwestern sides. The whole structure of the atoll, in other words, seems to have been superimposed upon the older and already existing surface of the guyots. Since it can, without too much license, be assumed that the other nearby atolls of the Marshall group developed simultaneously with Eniwetok, their slopes might be examined for ± 700 -fathom

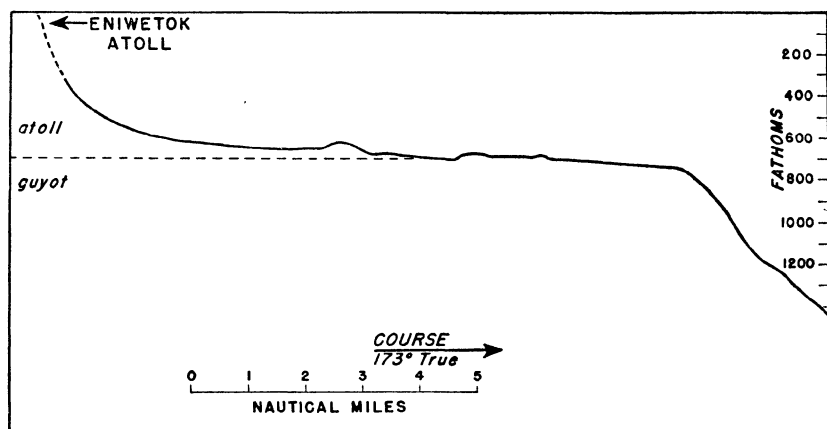


FIGURE 8.—Tracing from fathometer recorder of traverse extending southward from Eniwetok showing the atoll presumably superimposed upon a guyot (A-A of figure 7).

benches for further substantiation of the age relations postulated above. Only two of these have been adequately charted, Majuro and Kwajalein, and neither of them shows 700-fathom benches. When it is considered that a relatively small atoll such as Majuro shows no bench at 700 fathoms while not very far away a guyot has a truncated upper surface 35 miles across, it is evident that Majuro could never have been subjected to the conditions which planed off the 35-mile-wide surface of the guyot.

PART II. THEORY

The writer has given a great deal of thought to the problem of origin of guyots since first encountering them in 1944. In part I of this paper the physical features of guyots, so far as they are known, are described. It now remains to account for them. During the past 2 years, many hypotheses were tried and discarded. Finally the writer

arrived at the hypothesis here presented. Though it explains the facts at present available, it is highly speculative and might easily be wrong. Nevertheless, it seems worth presenting as a working hypothesis, particularly since it has many interesting ramifications, some of which would be worthy of investigation even if the parent hypothesis were found to be invalid.

EXPLANATION OF DEVELOPMENT OF UPPER SURFACE OF GUYOTS

When the writer first discovered guyots, he supposed that they were drowned atolls. However, this hypothesis proved untenable upon

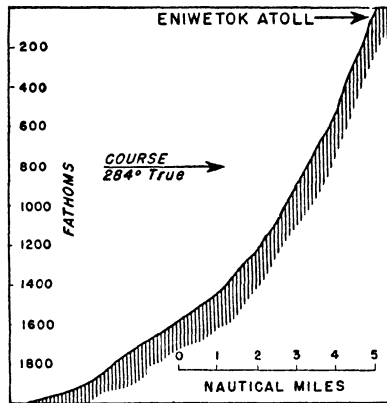


FIGURE 9.—Profile B-B of figure 7 showing normal atoll slope approaching Eniwetok from the East.

further study. A profile of an atoll should show a rise along the outer margin representing the area of active reef growth and should be dished in the middle—the lagoon—unless it were filled in with younger sediments. On an atoll, the profile breaks abruptly outside of the living reef and descends in slopes averaging about 25° . There is no feature comparable to the gently sloping shelf found around the flat tops of nearly all guyots. In fact there seems to be no way of accounting for these shelves unless the guyots had developed in a sea which did not support reef-building organisms.

It may reasonably be assumed that guyots were originally volcanic peaks. After a long period of time they became stabilized and were eroded down to low relief. At this time they developed gently sloping shelves around them as might be expected in the case of a maturely dissected island. This was followed by a long period of marine planation, unhampered by reef growth, ultimately forming the flat upper surfaces. If marine planation cut the island down to about 30 fathoms below sea level, then the outer margin of the gently sloping

shelves, normally some 70 fathoms deeper, would have originally represented approximately a 100-fathom curve around the island.

Possibilities of accounting for the reef-free surface of the guyots by some connection with a glacial epoch were considered and rejected. If reef growth had been inhibited by a glacial epoch, the guyots would have had to have suffered marine planation followed by sudden subsidence to below the level at which reef growth would recommence at the end of the glacial epoch—a coincidence which makes the hypothesis very unlikely. The glacial epoch would have had to be a very long one to permit complete planation of the larger guyots. It cannot possibly be referred to the Pleistocene epoch since the Marshall Islands atolls are younger than the guyots and there could obviously not have been time for marine planation, subsidence, and upbuilding of the atolls

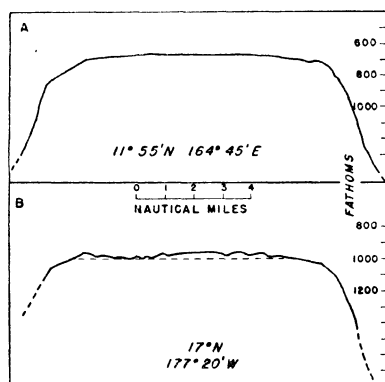


FIGURE 10.—Profiles across two guyots. A is normal except that the gently sloping shelf is lacking on the right-hand side; B is an example of the hummocky type of upper surface.

all in this short epoch aside from the inconsistency that the cold water was called upon to keep the guyot surface reef-free but later on permitted the upbuilding of the atolls.

GENERAL RELATIONS WITHIN PACIFIC BASIN

Since it is difficult to discuss any theory of origin of guyots against the background of misconception and ill-founded theories which at present confound geologic literature on ocean basins and the Pacific Basin in particular, the writer proposes to wipe the slate clean and start on a new basis.

The Pacific Basin is here considered to comprise the central portion of the ocean and is bounded by an almost continuous belt of strong late Cretaceous-Tertiary mountain building. On the northern and western borders this belt is characterized by elongate deeps which lie over downbuckles of the earth's crust.³ Related island arcs show

³ See the works of Vening Meinesz and others on gravity at sea.

intense volcanic and seismic activity.⁴ On the eastern margin are found the cordilleras of the North and South American west coasts and on the south little-known Antarctica. The volcanic rocks of the islands of the Pacific Basin are dominantly basaltic, whereas those related to the island arcs and their uplifted cordillera equivalents are dominantly andesitic. The area of arcs and cordilleras bordering the Basin is tectonically the most active and unstable area of the earth's crust today. The Pacific Basin itself seems to be tectonically a most stable area and possibly has been throughout geologic time.⁵ One encounters no evidence of folding anywhere over its broad expanse. Though fault scarps can be found, their rarity bespeaks great stability. Seismic activity in the Pacific Basin is almost nil.

The writer favors Buddington's (1943) concept of the nature of the earth's crust and considers that the suboceanic crust probably consists of horizontally layered rocks including such types as norite, gabbro, anorthosite, pyroxenite, peridotite, dunite, and probably some eclogitic facies. These are relatively strong rocks—stronger than the granitic to quartz dioritic rocks which presumably make up the "granitic" layer of continents. The writer believes the oceanic crust is very strong though this opinion is at variance with existing textbooks and much of the current literature. However, Jeffreys (1929), Daly (1940), and Longwell (1945) all favor a strong oceanic crust. The only bases for judging its strength are its behavior and the strength of the rocks of which it is thought to be composed. Both of these indicate strength. The reason it has been generally considered to be weak, appears to be related to calling it the exposed sima or the basaltic substratum and consciously or unconsciously bringing in Daly's theory of a weak glassy basaltic substratum. But Daly postulated a strong crust and weak substratum at considerable depth. Those favoring the hypothesis of continental drift assumed a very weak basaltic crust below the oceans without, so far as the writer is aware, presenting evidence other than the hypothesis of drift to substantiate assumption.

⁴ There is general agreement as to the position of the "andesite line" along the western margin of the Pacific Basin except for the area of the Carolina Islands. Some place these inside and some outside of the "andesite line." The writer tentatively includes most of the Carolines in the Pacific Basin and traces the "andesite line" down their western margin including Ulithi, Yap, Ngulu, and the Palaus behind—on the west side of—the "andesite line." This is essentially the same as the line drawn by Hobbs (1944).

⁵ Having obtained considerable first-hand information in the Pacific during the past few years the writer must now revise the views expressed in Betz and Hess (1942). The tentative trend lines shown on the chart should be considerably reduced in number by eliminating practically all of northeasterly trends. Further development of the bottom topography shows that they do not exist. The hypothesis that certain linear groups of islands and shoals, particularly the Hawaiian group, lie along a major earth fracture which may be a strike-slip fault is retained. The relationship on a small scale of the volcanic activity to fractures has been demonstrated by Stearns and MacDonald in Samoa and Hawaii. The trends of these fractures are approximately parallel to the elongation of Samoa and the elongation of the Hawaiian chain.

Many authors have correlated the observation that island arcs (and hence mountain building) develop in the ocean basins along the margins of continents with the concept that the continental massifs are strong and the oceanic crust weak, thereby accounting for the localization. However, if mountain-building forces are related to

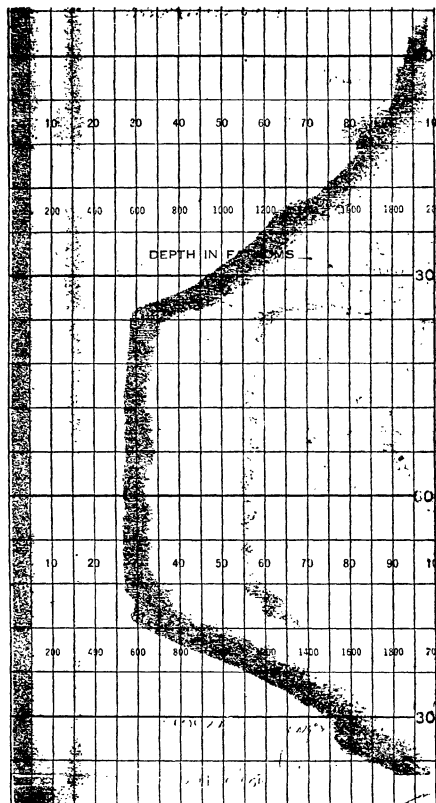


FIGURE 11.—Fathometer recorder trace of guyot in latitude $14^{\circ}20'$ N., longitude $165^{\circ}55'$ W. Ship's speed, 13.7 knots; course 059° true.

convection currents within the earth (Griggs, 1939), the most satisfactory of the present theories, then the localization can more reasonably be explained on the basis of heat relations within the crust. Being warmer under continents and cooler under oceans the downward-flow part of the convection cell would be more likely to be localized under the ocean and would be supplemented in some cases by the outward flow of warm material from beneath the continental area.

Having concluded that the Pacific Basin was in general strong and stable, it is now appropriate to turn to exceptions in detail to these generalities. All volcanic islands of the ocean basin proper (excluding from this discussion the highly unstable island arc areas) are subject to frequent vertical movements as long as vulcanism is active.

In this sense they are unstable. The expansion during magma generation, injection of magma into the crust below the volcano, crystallization of magma and contraction, extrusion of magma from a central vent and isostatic adjustments to the load, out-flow of weak oceanic clays from beneath the volcanic load, etc., all tend to result in vertical movements of the volcanic island. Such islands may have terraces

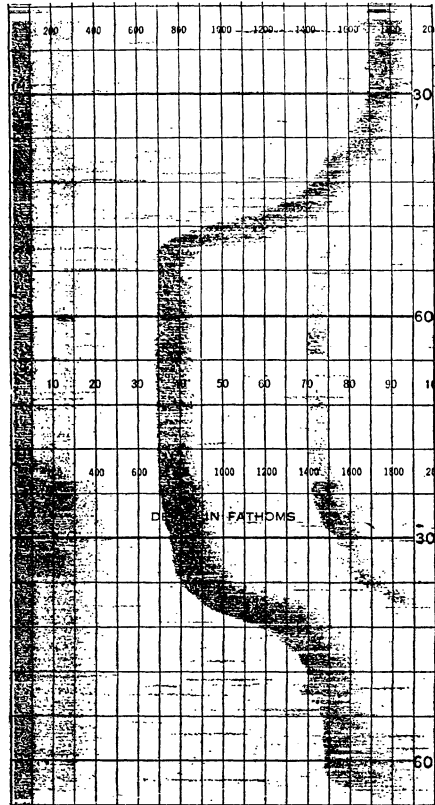


FIGURE 12.—Fathometer recorder trace of guyot near latitude 21° N., longitude 173° E. Ship's speed, 13.5 knots; course 059° true.

extending to hundreds of feet above sea level and at the same time have drowned shore lines and exhibit a series of submerged terraces as well. Once this vulcanism dies, the island will probably become stable. Of the hundreds of atolls and banks with their volcanic pedestals beneath them, one can find very few in the Pacific Basin which have had their coral reefs uplifted by as much as 150 feet.*

* Vening Meinesz (1941) reexamines gravity data for oceanic islands. Though large, local, positive, isostatic anomalies are found on such islands, the regional anomalies show that such small islands are regionally and not locally compensated and thus closely approach isostatic equilibrium. This indicates a geologically rapid adjustment to the disturbance of equilibrium brought about by vulcanism.

Aside from vulcanism and its effect of producing local points of instability, convection currents of lesser intensity than those producing island arcs may result in vertical movements of the suboceanic crust at times.

HYPOTHETICAL DEVELOPMENT OF THE HISTORY OF THE PACIFIC BASIN AND THE ORIGIN OF GUYOTS

Most discussions of Pacific historical geology jam all the known history into the late Tertiary, Pleistocene, and Recent ages. To be sure the rocks visible on the surface of volcanic islands are mostly very young, predominantly Recent plus some Pleistocene, and very rarely rocks that can be demonstrated to be as old as Tertiary. Many writers seem inclined to place Pacific atoll formation in the Pleistocene though others extend it back into the Tertiary (Stearns, 1946). On the other hand, the Pacific Basin is generally considered to be very old, probably dating from early pre-Cambrian time (Kuenen, 1937). It seems reasonable to suppose that volcanic activity in the Pacific Basin and hence island formation has gone on sporadically since early pre-Cambrian. Where then are the pre-Cambrian, Paleozoic, and Mesozoic islands? In order to answer this it is necessary to digress along several other channels.

Any island formed in the Basin can be assumed to have begun as a volcano or group of volcanoes. After vulcanism ceased and the island had become stabilized, the following sequence of events would necessarily take place. The island would be eroded to low relief, and after a long period of time (providing growth of reef-forming organisms did not interfere) the island would completely disappear as a result of marine planation. Such must have been the fate of all pre-Cambrian islands before reef-forming organisms existed.

Kuenen (1937) and (1941) has concluded that there has been little change of sea level since early pre-Cambrian time. He estimated that the rate of sedimentation in the deep sea is approximately 1 cubic centimeter in 10,000 years for red clay, since the end of the pre-Cambrian, and 1 cubic centimeter in 5,000 years for globigerina ooze. Since most of the material deposited on the ocean floor has ultimately come from the continents, isostatic adjustment of the load on the sea floor and the loss of weight from the continents has resulted in the sinking of the former and rise of the latter so that the relative sea level with respect to the continents has not changed very much. One obviously cannot put a layer of several thousand feet of sediments into the oceans without causing the water to rise by an equivalent amount (less the water included in pore space in the sediments). Thus, quite apart from the discussion of isostatic adjustment mentioned above, every centimeter of sediment put into the ocean causes sea level to rise with respect to an oceanic island by just a little less than a centimeter (less by the

amount of water in pore space of the sediment). Even though the figure cited for the rate of sedimentation may be inaccurate it nevertheless follows that oceanic islands are and have always been slowly sinking relative to sea level.

It stands to reason that once lime-secreting organisms appeared in the oceans, presumably in Cambrian time they would grow upon any available shallow, wave-cut platform and both tend to protect it from further wave action and build it up to sea level. These reef-forming organisms need not have been very efficient reef builders to keep pace with a settling rate of 1 cubic centimeter in perhaps 5,000 years. So

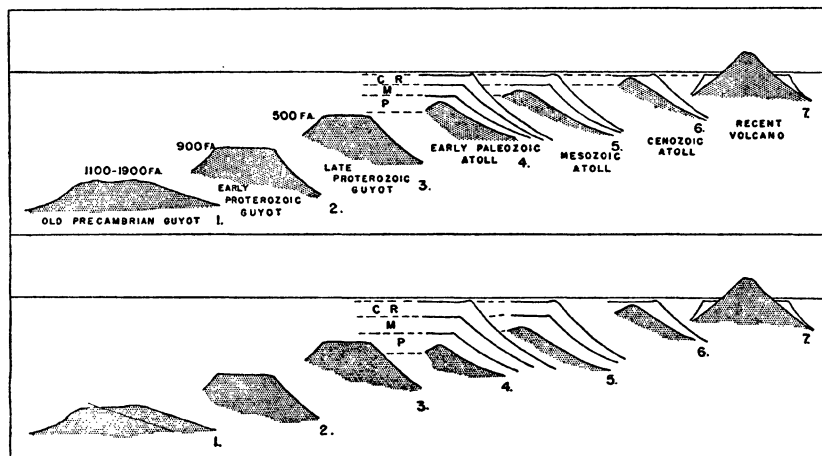


FIGURE 13.—Sequence depicting diagrammatically guyots and atolls in steps of decreasing age. C R stands for Cenozoic and Recent; M, Mesozoic; P, Paleozoic. In upper half of diagram the effect of the limestone load on atolls is neglected to illustrate the original depth relations to the volcanic foundations. In the lower diagram the effect of load has been added.

that beginning in Cambrian time every island in warm seas which at that time had not been submerged below the level at which these organisms could live, would be built up to sea level or nearly to sea level and could henceforth maintain its growth. In other words all Paleozoic, Mesozoic, and Tertiary islands which were eroded to low relief and submerged in warm seas must inevitably become banks or atolls and be maintained as such throughout the remainder of geologic time except for the interference of some rare diastrophic accident. Epochs of glaciation might inhibit growth of reef-forming organisms temporarily. But these epochs are too short to permit the islands to sink to such a level that growth would not recommence with the return of warmer water.

We may now turn to the ultimate objective of this long series of digressions, the guyots. It is proposed that they represent the relics

of pre-Cambrian islands formed by the processes suggested above. The group of guyots with which we have been mainly concerned range from 520 to 960 fathoms (3,120 to 5,760 feet) below sea level. Accepting Kuenen's figures for accumulation of sediments, at least 2,000 feet of sediments (solid) would have been deposited in the deep sea since pre-Cambrian time. The great bulk of sediments, however, are deposited along continental margins, on the shelves, slopes, and shallow epeiric seas. It is almost impossible to estimate the amount of water displaced by these inasmuch as a thickness of tens of thousands of feet may displace only a relatively small amount of water since the bottom of such basins of sediments tend to sink isostatically under the load. These thick prisms of sediments may at a later time be deformed and welded to the continents, thereby enlarging the continents at the expense of the oceans. Certainly these processes have decreased the areal extent of the oceans a considerable if unpredictable amount since the end of the pre-Cambrian. If sediments deposited in shallow waters around the continents displaced only half as much water as deep-sea sediments, an estimate which seems to the writer to be on the conservative side, then one could account for a rise of sea level relative to an oceanic island of 3,000 feet (500 fathoms) since the end of the pre-Cambrian which is comparable to the present depth of the shallowest guyots. Thus we might attribute most guyots to a Proterozoic episode of vulcanism. The occasional, less well-preserved surfaces mentioned in the text, having depths between 1,100 and 1,900 fathoms might be older and well back in the pre-Cambrian in age.

RECOMMENDATION FOR FUTURE RESEARCH

With the above hypotheses in mind it would be exceedingly interesting to drill a hole 5,000 feet deep in the center of a Pacific Basin atoll. It is necessary to avoid the outer margin of the atoll since it may well have built outward over its own debris. From another point of view, a hole drilled on the southern rim of Eniwetok would almost certainly penetrate into the underlying guyot at a depth of approximately 4,200 feet. It would be extremely interesting also to make magnetic surveys of a number of atolls to estimate the depth to the volcanic core and perhaps couple such an investigation with seismic and gravimetric work. Bottom samples with the Piggot sampler taken from the flat tops and gentle marginal slopes of guyots might bring up some of the rock of which they are formed, provided these surfaces had been swept completely clean of sediments. Pleistocene to Recent banks in high latitudes where cold water would inhibit growth of reef-forming organisms should be investigated to compare their profiles with those of the guyots. A further investigation of Murray's seamounts in the Gulf of Alaska might furnish some of the missing clues to the origin

of guyots, and might, if the hypothesis here presented is correct, show features exactly comparable to guyots but at depths shallower than 500 fathoms. At the latitude of the Gulf of Alaska the water may have been too cold for reefs to grow on the platforms.

ACKNOWLEDGMENTS

The writer wishes to thank Dr. J. Brookes Knight, Prof. F. A. Vening Meinesz, Prof. A. F. Buddington, Prof. Charles Steel, and Dr. J. C. Maxwell for reading the manuscript and offering numerous valuable criticisms. The writer also wishes to express his appreciation to his quartermasters on the U. S. S. *Cape Johnston* for the care with which they took soundings while at sea, in particular QM1/c Robert Kiefer, QM1/c R. K. Pritchard, QM2/c H. Jensen, and QM3/c Frank Grumblatt. W. Miner Buell, Jr., of the Hydrographic Office, United States Navy, was very helpful in collecting data on ocean-bottom features from documents in the Hydrographic Office, and many of the data were plotted by Ensign William Roche and Miss D. Trussell of that office.

FURTHER COMMENT ON GUYOTS AND ATOLLS IN THE LIGHT OF RECENT INFORMATION

Since the above paper was first written investigations of Bikini Atoll have yielded important information, in particular the seismic profiles reported on by Dobrin, Snively, White, Beresford, and Perkins (1946). Further comment seems desirable on the problems suggested by this information.

The seismic profiles indicate the presence of a rock comparable to basalt below the atoll. This high-velocity material reaches a maximum depth of 11,000 feet on the eastern side of the atoll, but rises to a depth of 5,500 to 6,000 feet not far from the southern rim, at a point slightly to the west of the north-south center line of the atoll. The western third of the atoll was not investigated during this survey. Since the highest point on the "basalt" surface lies on the western margin of the area investigated, it is possible that this "basalt" rises to a level nearer the surface somewhere in the vicinity of the western or southwestern rim of the atoll.

It is evident from the survey that the volcanic core of the atoll forms a peak located eccentrically with respect to the present atoll structure. Textbook diagrams have led most of us to expect that the volcano would be nicely centered beneath the lagoon. A logical consideration of the proposition would have indicated that the peak of the volcanic core should lie not under the center of the atoll, but more or less displaced toward the lee side with respect to the prevailing winds, for reef growth is more rapid and vigorous on the windward side. The same conclusion was implicit in the results of the Royal

Society investigation of Funafuti (1904). In that case a magnetic survey was made before the boring was attempted. The results showed a magnetic high close to the western margin, on the lee side. It was, therefore, deemed desirable to drill on the western margin, but unfortunately it was not possible to get the equipment on this location so the boring was made on the eastern rim instead. (See figs. 14 and 15.)

In 1944 the writer found a guyot centered about 20 miles northwest of Bikini and made four NE.-SW. profiles across it. During the Crossroads Operation the Navy surveyed this guyot, making a number

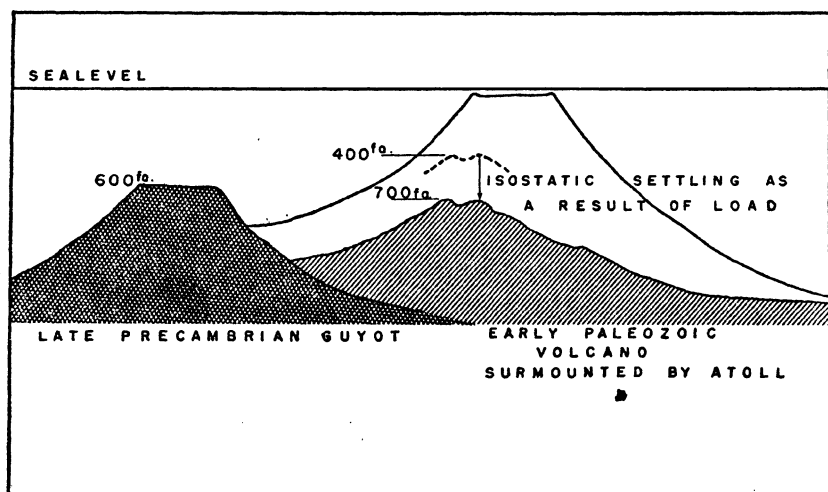


FIGURE 14.—Relations between the top of a late Pre-Cambrian guyot and the volcanic core of an old Paleozoic atoll. Settling because of loading by limestone has depressed volcanic core of the atoll below the level of upper flat surface of guyot.

of NW.-SE. sounding traverses over it, so that its outline and form are now well known. It has a flat upper surface at 700 fathoms (4,200 feet) and is separated from the northwestern slope of Bikini by a low saddle.

If the writer's hypothesis were correct, that the surface of the guyot became submerged in pre-Cambrian time before the appearance of reef-building organisms, how could nearby Bikini Atoll have grown up from a peak which is now deeper, i. e., 5,500 feet below sea level? This peak would be more than a thousand feet below the top surface of the guyot. It might be supposed that the peak under Bikini comes much closer to the surface west of the investigated area, and therefore might have been both younger and higher than the adjacent guyot surface. Thus it would have been able to support reef-building organisms after the guyot was planed off. However, let us disregard this possibility for the moment and consider the more fundamental

relationships which should apply to the depths of guyot surfaces with respect to the depths of atoll cores. According to the writer's hypothesis, the atoll cores should be younger than the youngest guyot surfaces and should have once projected sufficiently above these surfaces (closer to sea level) so that lime-secreting organisms would grow upon them. Considering the Bikini results, it is evident that an old atoll will have many thousands of feet of limestone deposited on its core. The mass represented by this material is in excess of that which the earth's crust could bear without yielding. Isostatic adjustment will, therefore, take place. As a result of this adjustment to loading, the peaks of the cores of old atolls must necessarily be considerably deeper than

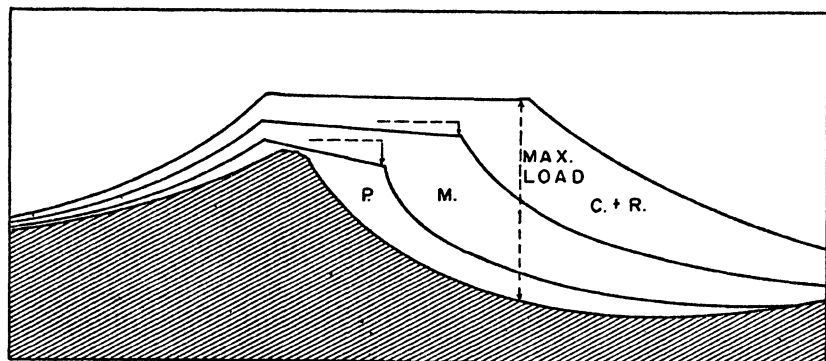


FIGURE 15.—Sketch showing the effects both of loading by limestone and of asymmetrical growth of atoll—more rapid growth to windward toward the right side of the diagram. Note that the high point of the volcanic foundation now lies beneath the lee side of the atoll and that the foundation has been tilted somewhat by the load. Overlying old atoll surfaces are also tilted but progressively less as the surface is approached.

the upper surfaces of the youngest guyots, as illustrated in the accompanying diagrams (figs. 13, 14, 15). The settling in the case of Bikini from this change might be estimated roughly as perhaps 3,000 feet.

There was implicit in the original paper a general theory of atoll development in *oceanic* areas. Island arc areas were specifically ruled out since they present a very different problem. Much confusion has resulted in the past from lumping the two. The theory was close to Darwin's original concept, but substitutes slow rise of sea level by partial filling of the ocean basins with sediment for subsidence of undetermined cause. True, there are many reasons why a young oceanic volcano should subside, such as isostatic settling of the load represented by the volcano, squeezing out of weak oceanic clays from beneath the volcano, consolidation by crystallization of the magma in the chamber beneath the volcano with consequent decrease in volume, etc. But all these are comparatively short-lived and could

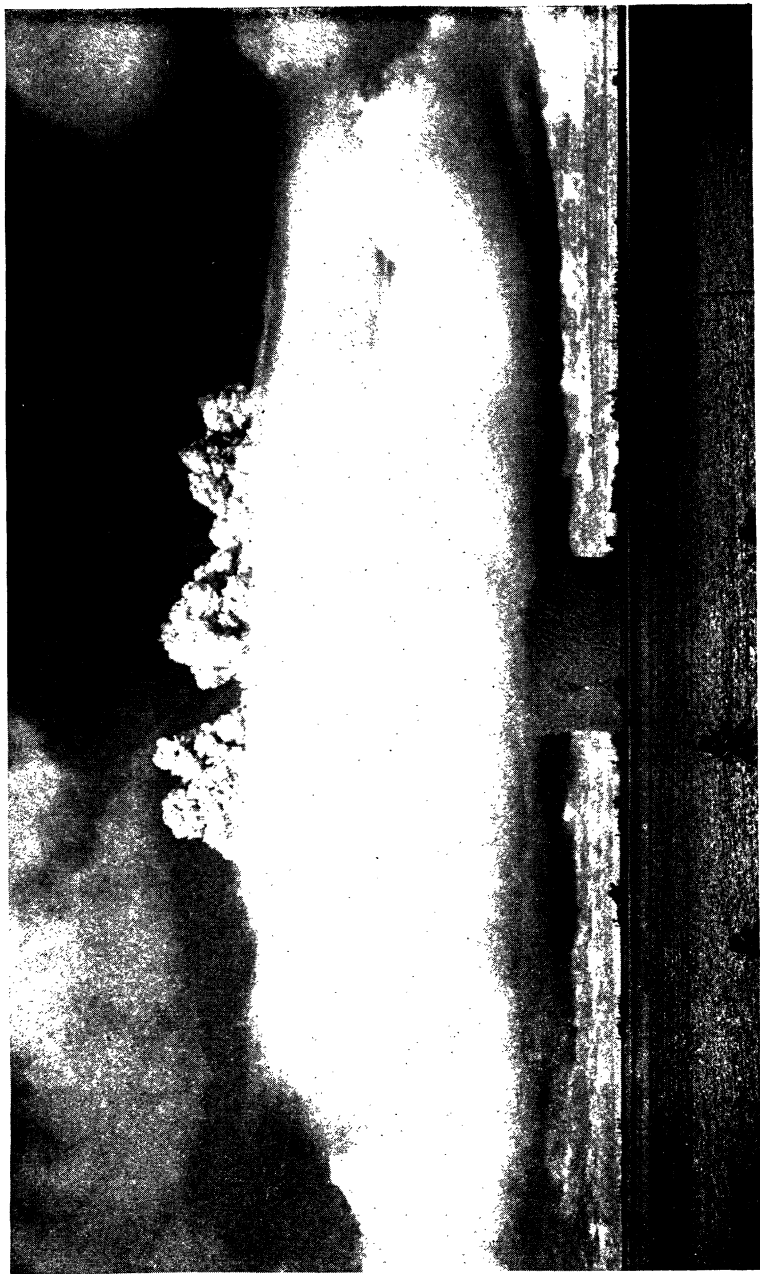
only explain subsidence in the early stages rather than the apparent long-continued relative subsidence of many oceanic atoll groups.

While the main mechanism of oceanic atoll formation as envisioned by the writer is the slow rise of ocean level, further subsidence of the atoll isostatically to compensate for loading by the limestone deposited is a necessary corollary. It is emphasized that this isostatic settling must be a secondary consequence and not a primary factor in atoll formation since the settling will always be much less than the thickness of the limestone deposited. More rapid reef growth on the windward side will ultimately result in the eccentric location of the underlying volcanic pedestal which is displaced relatively toward the lee side. This also causes eccentric loading, as shown in figure 15, and should result in a tilting of the original volcanic core and of old, now deeply buried, atoll surfaces.⁷

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⁷ Since preparation of this discussion, the report on drilling of Bikini Atoll has been presented before the Geological Society of America (Ottawa, December 1947) by Ladd, Tracey, Lill, Wells, and Cole. Calcareous sediments were found to the bottom of the hole at 2,554 feet. Miocene fossils were identified from 1,305 feet. The hole was drilled on the windward side of the atoll where the thickest Cenozoic section should occur (see fig. 15 above).



THE UNDERWATER ATOM BOMB EXPLOSION IN THE LAGOON AT BIKINI, JULY 1946

THE BIOLOGY OF BIKINI ATOLL, WITH SPECIAL REFERENCE TO THE FISHES

By LEONARD P. SCHULTZ
Curator of Fishes, U. S. National Museum

[With 17 plates]

The fourth and fifth atomic bombs were exploded over and in Bikini lagoon in 1946. A year later in 1947, the palms were still waving in the tropical breeze, the pandanus was fruiting, the tacca or arrowroot formed tubers in the soil, and a new plant, the papaya, was bearing delicious fruit. It had sprung from seeds left by the retreating hordes of men. A lone dog wandered on Bikini Island, a cock was crowing on Enyu Island, and the little brown rat was scampering about at night. Birds flew overhead and fishes swam in the lagoon nearly as abundantly as a year ago.

Along the outer edges of the reefs in the crashing and foaming surf life went on as before. The large purple slate-pencil sea urchins, holding their positions by bracing their spines into crevices and irregularities, were everywhere along the lithothamnium ridge. Farther inward on the flat area in broad, shallow depressions were vast numbers of the black sea cucumber, often concentrated by the dozens in pools. Ghost crabs, leaving their sandy burrows at night, ran along the sandy beaches. Their slower relatives, the hermit crabs, labored along, carrying heavy snail shells on their backs. On land the nocturnal coconut crab came from hiding to feed on the coconut, or the female went down to the sea, to dip her tail into the water, causing thousands of eggs to hatch the moment they were moistened.

Yet, with all this life going on normally at Bikini, one should not feel a false sense of security; the atomic weapon is terrible. The radiations emanating from the isotopes resulting from the atom bomb explosions are dangerous to animal and plant life. The lower animals can withstand greater amounts of radiation than the vertebrates, but, among the latter, man and the other mammals are most sensitive.

The explosion of the Baker Day blast was so powerful that it could have lifted an entire fleet of battleships high into the air as easily as a summer wind blows thistledown across a field. The concussion in a limited area from such a sudden explosion caused great mortality

among aquatic life; hundreds of dead and dying fish were seen floating in the lagoon waters shortly after and for a few days. Great quantities of oil were released from the stricken ships. It floated and was driven by the wind onto coral and algal growths, smearing shellfish and echinoderms on the reefs, causing additional mortality of organisms in limited areas.

BIOLOGICAL EXPEDITIONS TO BIKINI

Under the direction of Commander Roger Revelle, U. S. N. R., and Lt. Comdr. Clifford A. Barnes, U. S. C. G. R., an expedition sailed from San Francisco in February 1946 on the U. S. S. *Bowditch*, returning to the United States in September. Assembled on this ship were numerous scientists representing the fields of biology, oceanography, and geology. It was the purpose of this group to map and study Bikini Atoll in a thorough manner before the explosions so that if the atomic bombs caused any profound changes these might be detected. As control atolls, extensive biological studies were made at Rongelap, Rongerik, and Eniwetok in the northern Marshall Islands.

A second expedition, the Bikini Scientific Resurvey, left San Diego July 1, 1947, on board the U. S. S. *Chilton* for the purpose of determining changes that had occurred as a result of the Crossroads Operation of 1946. This resurvey, made under the direction of Capt. C. L. Engleman, U. S. N., returned on September 11 to San Diego.

The biological field work in the northern Marshall Islands consisted of making extensive collections of the flora and fauna, and of taking statistical samples of the populations of the marine animals.

The botanical studies were made by Dr. William R. Taylor, University of Michigan, during 1946. In 1947 the physiology of aquatic plants was undertaken by Drs. L. R. Blinks and P. M. Brooks, Stanford University, California. The marine invertebrates were studied by Dr. J. P. E. Morrison and F. M. Bayer of the Smithsonian Institution, Washington, D. C. During July and August 1947, Dr. D. M. Whitaker, Stanford University, made special studies on the echinoderms; Dr. A. C. Cole, University of Tennessee, on the insects; and Dr. Robert W. Hiatt, University of Hawaii, on the food of fishes. Dr. M. W. Johnson, Scripps Institution of Oceanography, made extensive collections of plankton, and Dr. D. B. Johnstone, New Jersey Agriculture Experimental Station, studied the microbiology of Bikini during 1946. The geology of Bikini and other Marshall Islands was studied by Dr. Harry S. Ladd, Dr. J. Harlan Johnson, Joshua I. Tracey, of the United States Geological Survey, aided by Dr. John W. Wells, Ohio State University, and Gordon G. Lill, Office of Naval Research, Geophysics Branch. Dr. K. O. Emery, University of Southern California, mapped the bottom geology of Bikini. The 2,556-foot deep hole was

drilled by the G. E. Failing Supply Co., under the direction of the geologists.

The study of the effect of radiation on marine animals, especially fishes, was made during 1946 and 1947 by the University of Washington group under the direction of Drs. Lauren R. Donaldson and Arthur J. Welander, School of Fisheries, Seattle.

Since fishes represented the group of animals of greatest economic importance in and around the atoll, emphasis was placed on them. Statistical studies were attempted in 1946 and 1947 with the view of measuring the relative abundance of fishes, those caught by trolling, and on the reef by other means. The pelagic kinds—tuna and their relatives—were caught by commercial fishermen, using trolling methods. This work was under the immediate supervision of John C. Marr and Osgood R. Smith, United States Fish and Wildlife Service. Similar population studies were made of the lagoon and reef fishes by Vernon E. Brock, director, Division of Fish and Game, Territory of Hawaii, Dr. Earl S. Herald, United States Fish and Wildlife Service, and Dr. Leonard P. Schultz, curator of fishes in the United States National Museum, Smithsonian Institution. The latter and Loren P. Woods, curator of fishes, Chicago Natural History Museum, are preparing a descriptive catalog of the fishes of the northern Marshall Islands.

BIKINI ATOLL AS A FISH HABITAT

Bikini Atoll in shape resembles a bathtub, except that its sides are cut through by several deep channels. It is about 22 miles long by 13 miles wide, inclosing a lagoon whose depth is mostly 180 feet with a few areas down to 200 feet. Rising from the lagoon floor are large coral heads, a few of which come near the surface, whereas around the margins of the atoll reef are more coral heads that reach the surface. The lagoon floor slopes gradually upward from its deeper parts to those areas exposed during the low tides. The bottom is composed of loose sand, fragments of calcareous algae, and coral remains, on which are growing a great variety of sessile invertebrates, aquatic algae, and into the rocky fragments worms burrow. In otherwise unused crevices, fishes hide.

SANDY AREAS

Considerable areas adjoining the rim of the atoll in the shallower parts of the lagoon are composed of loose sand. In places where this sand is continually shifting, no corals occur, but where it remains stable small isolated ones from a few inches to 2 or 3 feet high occur. These areas are somewhat barren of fish life.

Usually around coral clusters are a few kinds of damsel fishes, one or two species of wrasse, scorpion fish, often gobies and blennies.

Small schools of the black-banded damsel fish, *Dascyllus aruanus*, when disturbed, seek shelter in closely branching coral heads. They remained within it while we broke loose from the bottom the entire growth in order to carry it ashore. There the coral, with its fish and crustacean inhabitants, was broken into fragments, and its denizens were picked up without a single individual escaping.

Swimming in schools over these broad, sandy stretches are yellow-streaked goatfishes, harvest fish, threadfins, jacks, mullets, lizard fishes, sand perches, and sometimes a few flatfishes (Bothidae). Cruising around individually are black-tipped sharks. In holes in the sand can be seen a species of large goby with a prominent blue streak across its cheek. Snake and worm eels burrow in the loose gravel and sand of the bottom. Giant tridacna lie on the bottom, with their beautifully iridescent mantles exposed to the flickering sunlight.

Big sting rays occasionally are seen on the bottom in 10 to 30 feet of water. Vernon E. Brock, assisted by Dr. Robert Hiatt, speared one off Eman Island in 20 feet of water, while skin diving. The capture of this dangerous fish, with its venomous sting, was a remarkable feat. Brock swam down over the fish and drove a spear into it, then grabbed the end of the spear, pulling the hundred-pound creature toward the surface, but had to come up for air, and it went down. Once again he tried, and this time with Dr. Hiatt's aid brought it up, all the time keeping away from the lashing tail of the ray. After a desperate struggle, it was speared again and finally brought alongside the rowboat from which they were operating. It is now preserved in the United States National Museum along with about 50,000 other fish specimens collected during 1946 and 1947 in connection with the atom bomb experiments.

CORAL AND ALGAL AREAS

From this somewhat barren sandy habitat, there occur all gradations in abundance of coral heads with algae up to the stage where they are so close together that there is scarcely room to step between them. More often the channels between the corals are 3 to 15 feet wide, and some reach 30 feet or more in width. This type of habitat may occur in the lagoon, in the wide passes, or on the ocean side of the atoll rim.

Where the corals and algal growths are luxuriant, over 200 species of fish occur and were regularly captured through the use of rotenone. However, during 4 hours' work, the maximum number taken at a single station was 136 at Erik Island, Bikini Atoll.

Although the smallest fish known, a fresh-water goby from the Philippine Islands, is not found at Bikini, one of its relatives is a close runner-up. The Philippine goby measured 9 or 10 millimeters (three-eighths of an inch), whereas the smallest Bikini fish, the goby

Eviota, when adult and sexually mature was 15 millimeters or five-eighths of an inch long. This contrasts sharply with a 10-foot wide manta ray weighing about 700 pounds, taken in Enyu passage. The largest fish, however, was caught by the commercial fishermen at Bikini in over 40 feet of water. It was a tiger shark measuring 13 feet 11 inches long, with an estimated weight of considerably over half a ton.

Living in the branching polyps of the coral *Acropora*, was the little yellowish goby, *Gobiodon citrinus*, which had during July and August prepared a nest and laid eggs in it. *Gobiodon* cleared off a small area, three-fourths of an inch by 2 inches long, at the base of a coral branch arising near the center of the colony. On this carefully prepared spot, a thin growth of green, purplish, or brownish-colored algae occurred.

Acropora responded to the presence of *Gobiodon* and formed a slightly raised rim around the nesting area. This goby, only about an inch long, then deposited a small cluster of eggs in the shallow depression and both parents remained to protect their home. Each egg was attached to a gelatinous substratum by a short adhesive stalk with the head of the embryo on the opposite end. Among these eggs, numbering 100 to 200, was a fine, branching, filamentous red alga. The oblong eggs were close together but not crowded.

Another remarkable association between a fish and an invertebrate host occurred in this same habitat. On the lagoon floor in a few feet of water down to depths of 20 feet or more lives a globular starfish, *Culcita novaeguinae*, that reaches the size of a man's head. We found in its body cavity, in about half of those investigated, a nearly transparent 6- to 10-inch-long eel-like fish—the pearlfish, *Carapus*. We kept one of them in a jar of water, noticing the very slow rate of respiration and its ability to live in sea water with a low amount of dissolved oxygen. Because *Carapus* was transparent, the circulation of the blood was observed clearly.

FLAT PAVEMENTLIKE AREAS

The nearly flat pavementlike areas on the atoll reef are carpeted with a layer of tiny foraminifera and vinelike algal growth, forming a mat 1 or 2 inches thick. West of Bikini Island, such a reef is transversed with numerous "cracks" or shallow grooves only a few inches deep. In other places there are vast areas incompletely drained during low water, leaving shallow tidal pools only an inch or two deep. In these occur a few species of blennies, gobies, and sometimes a large number of the blackish sea cucumber. Whenever these depressions retain about a foot of water, corals begin to grow and the animal life increases.

As the tide rises and the surf breaks over the lithothamnium ridge, then surges several inches deep across this flattened part of the reef, great schools of blue-green and dark-red parrot fishes, *Scarus*, often with their backs exposed in the shallow water, move about on the reef, grazing like a herd of sheep on the algae growing there. Their tooth marks, remaining on the rocks, are easily observed. When the water deepens to a foot, surgeon, needle, trumpet, halfbeaks, damsel, goat-fishes, mullet, and dozens of other kinds appear. The black-tipped shark, *Eulamia malanoptera*, with its black-tipped fins sometimes exposed, cruises around on the reef, too. Although they are speedy swimmers, a man with a rubber sling and spear, or with a gun, may capture them without difficulty.

ISOLATED TIDAL POOLS AND SOLUTION CHANNELS

Around the shores of certain islands are small tidal pools and solution channels that are eroded in the limestone beach rock. They remain more or less filled with water at low tide. These depressions are from a few inches to a foot deep, with rounded smooth sides. They vary from a few inches to a few feet in width. Some appear as shallow pot holes but with the seaward side cut away. On the bottom in favorable places were accumulated coral fragments and occasionally pieces of beach rock.

During the period of low tide, several kinds of blennies appeared to be trapped in the pools. They remained motionless with their tails curved to one side, then suddenly, when disturbed, would flip through the air from one pool to another over the rocky ledges. Their agility and speed of traveling over "dry land" astounds one on his first visit to a reef. The young of *Kuhlia*, mullets, and damsel fishes regularly remain in these shallow pools. The goby *Bathygobius* is a frequent inhabitant, too. Hiding or trying to hide among the loose beach rocks and in the pools was the black speckled moray eel, *Gymnothorax picta*, sometimes curled between black sea cucumbers. As the incoming tide rose and refilled the solution channels and pools, the dark-banded damsel fish, *Abudefduf septemfasciatus*, returned to its favorite habitat along the very edge of the beach rock.

LITHOTHAMNIUM RIDGE

The outer margin of an atoll rim on the ocean side usually consists of the slightly raised pink to red-colored lithothamnium ridge contrasting beautifully with the deep blue ocean beyond. It is dissected by rugged surge channels and deep pools often 20 feet deep directly connected with the ocean. This ridge, creviced and pitted with holes, is about a foot or two higher than the flat part of the reef farther inward and varies in width from 40 to 100 feet. At extremely low

tides it is exposed except as the surf crashes over it, then some of the water is forced back over the flat part of the reef, flowing seaward again through the surge channels.

Some of the surge channels, extending for 100 feet or more back into the solid reef, are more or less roofed over or with perforations large and small through which the water may pour or spout on the incoming surge of a wave. They are lined with rich green and red algae, blue, red, yellow, and green corals, and a host of brilliantly colored fishes live in these clear waters.

The red calcareous algae forming the chief surface growth on this ridge were minutely pitted and creviced. Living among these perforations were several fishes, characteristic of the area. The little blunt-headed blenny, *Cirripectes*, appeared to favor this habitat, along with pseudochromids, especially *Plesiops*. Numerous too was a little viviparous orange-colored brotulid, several kinds of wrasse, eels, and small filefishes and puffers.

In the surge channels were the pempherids, surgeon and butterfly fishes, and hiding during the day in the dark crevices were the bright red soldier or squirrel fishes that come out at night to feed. Invertebrates characteristic along this narrow zone were the slate-pencil sea urchins and in the deeper crevices and pools the venomous sea urchin with its long, purple, needlelike, poisonous spines. Octopi were common, along with several kinds of shrimp and crabs.

OPEN-WATER HABITAT

Contrasted with the atoll rim and its coral-algal growths was the open-water habitat of the atoll, in which a great variety of fishes thrived that never sought the protection of the reefs. In these waters occurred very small fishes, moderate-sized ones, and the giants. Some are predaceous—the tunas, jacks, and sharks—whereas others, such as the manta and the round herring, lived by feeding on the small pelagic organisms in the water. This latter species, 2 or 3 inches long, occurs in big schools. It was seen daily near the ships anchored in the lagoon.

Cruising slowly around Bikini lagoon, one saw now and then big manta rays. However, in the middle of the broad Enyu channel, during 1946 and 1947, almost every day one to several occurred at the surface with the tips of their broad pectoral fins moving slowly up and down.

To capture one of these giant fish, 10 feet across, required preparation. A spear, fitted on the end of a long wooden shaft, with lines attached, was made. To the spear point was fixed about 75 feet of tiller rope lashed to an empty steel drum with the excess rope wound around it. This gear was then placed at the bow of a picket boat,

in a favorable place for throwing the spear the moment a big ray was approached. Standing poised, a man cast the spear into the head of a big fellow. The pole came out of the spear point, and was hauled aboard by the attached line. The tiller rope unwound from the floating drum as the ray sounded. Then, for nearly half an hour, the big manta tired itself out on the floating buoy. Finally, it was killed by rifle fire.

This harmless ray measured 9 feet 8 inches across and took 8 men to haul it up on the deck of the boat. It has at the front of its head, on each side, a long fleshy cephalic lobe, used to direct a current of water into its big, almost toothless mouth. This pair of lobes resembles the wings of the trawl and served the same purpose. Within the mouth, along the sides, are very fine-meshed gill rakers, serving to strain the planktonic organisms from the sea water that passes in the mouth and out the gill openings. The stomach of this big ray contained a few quarts of larval crustaceans.

Another group of fishes, the sharks, attracted attention. Although several kinds were encountered, such as tiger, bullhead, and whaler sharks, the most common were black-tipped, white-tipped (fins), and the gray shark. The latter species, not exceeding 7 feet in length, outnumbered all the others.

One night in Boro Passage, a picket boat was anchored for the purpose of catching sharks. Tuna fish caught that day by trolling along the outer reef and through the passages were passed through a small sausage grinder, and the chopped up meat and blood was cast slowly into the channel waters that were flowing outward. Within a short time, sharks were chummed to the boat by the presence of blood in the water. Then chunks of tuna meat, the size of a man's fist, were thrown into the water and others placed on big steel hooks.

The gray sharks struck these baited hooks with greed and speed. They jumped from the water. Several would rush the bait and each other as they fed voraciously. At the end of a few hours, 29 sharks measuring from 3 to 7 feet had been successfully landed on the boat.

USE OF ROTENONE IN COLLECTING REEF AND LAGOON FISHES

Methods of collecting fishes at Bikini included baited hook and line, trolling, spearing, dredging, attracting them to a surface light at night, and the use of various nets. The most important was the use of powdered plant roots to stupefy fishes, and since our methods of using it on coral reefs are unpublished, they are herein described. Powdered cubé or derris root with 5 percent of rotenone content has been used by various ichthyologists for nearly 40 years to collect fishes for scientific purposes. Dr. Carl H. Eigenmann, during field work in South America in 1908, probably was the first ichthyologist to

use vegetable poisons, although aboriginal natives in nearly all parts of the world have made use of them. Since that time most American ichthyologists have used vegetable poisons to collect fishes for scientific purposes. Drs. Eigenmann and W. R. Allen, University of Kentucky, describe methods of collecting fresh-water fishes in their 1942 publication, "The Fishes of Western South America."

From 1936 to 1938 the author experimented with the use of powdered derris root in fresh-water streams, and during the second World War, with the rotenone extract; the latter, however, did not appear to be as effective as the powder. It was not until 1939 that an opportunity came to carry on extensive experiments. Upon arrival in the Phoenix Islands, he found practically no enclosed tidal pools, the type of habitat in which ichthyologists had previously used rotenone fish poisons in small quantities. The reefs were flat, pavement-like structures, with narrow to wide channels, connected with open water, whereas the deepest isolated pools left at low tide were only a few inches deep and often lacked fish.

A large variety of fishes could be seen swimming in the channels, in the open waters, and even in the ocean surf. These had to be collected somehow. After carefully studying the currents and estimating the depth of water, the author attempted the use of rotenone in the open water among the corals and algae. At the end of July 1939, after 4 months' continuous work in various coral-reef habitats, methods of using rotenone in open-water situations had been perfected and, as a result, over 14,000 excellent fish specimens were recovered for the United States National Museum.

When the author was asked late in 1945 about obtaining samples of shallow-water reef fishes at Bikini, Operation Crossroads, for purposes of determining the relative abundance of fishes before and after the atomic explosions, he suggested the methods developed in 1939. A few months later, during March to August 1946, and again in July and August 1947, fishes were collected by the use of rotenone. Different techniques were applied depending on the situation. As a result, there were taken over 70,000 fish specimens on which systematic and population studies could be based. Part of these were discarded after data from them were recorded.

Thirty-five minutes before the tide reached its lowest point, the dry powdered root was placed in buckets or any suitable containers and mixed with water to a thick chocolate malted milk consistency, allowing about 20 minutes for one man to mix 25 pounds. By squeezing and stirring with the hands as water was gradually added, the powder soon formed a thick mud. Ten minutes before low water, the distribution of the mixture began. The stupefying of a great variety of fishes with rotenone was most successful at the lowest stage of water.

The success of this operation depended on determining the strength

of the currents and depth of water. A little of the mixture was tossed into the water and the direction of movement of the small, light brownish cloud, watched. After several such tests, assistants, each with a bucket or two of the mud, were stationed in the water and the distribution began. In water 4 to 5 feet deep, with a slow current, the mud was thrown out, permitting the little pellets to dissolve as they settled toward the bottom, forming a light brownish cloud. Twenty-five pounds of the dry powder formed a cloud about 100 to 150 feet long by 50 to 75 feet wide. It was highly effective if it took 10 minutes to pass any one point in water above 80° F. When used at lower temperatures the fishes must be exposed for a longer time. Usually a part of a bucket of the mud was reserved to strengthen the cloud after it had traveled a few hundred feet. This precaution was advisable, since the currents did not always behave as predicted.

SHALLOW-WATER REEF

Through experience it was learned which shallow-water habitats (to a depth of 10 feet) were suitable for collecting fish with rotenone. An area with an abundant growth of coral heads in about 3 to 4 feet of water, down to 10 feet in pools, with narrow to wide channels between the various kinds of corals, and a wind blowing the surface water more or less shoreward, was the most ideal situation.

Many kinds of fishes in the areas treated floated for a few minutes, then sank to the bottom. Some were picked up while they were violently swimming more or less in circles. A greater quantity of fish appeared at the surface than were recovered immediately. Those that drifted ashore were recovered, but those that got over deep water were often lost.

Immediately after introducing the rotenone, recovery of the fish started, but it was inadvisable to enter the area in which the treated water would flow, since that drove the unaffected fishes away. As soon as the water cleared, those fishes that settled to the bottom were collected. Two or three men continually wandered over the treated area, picking up the specimens in fine-meshed, bobbinet dipnets, 14 or 15 inches in diameter and 25 to 30 inches deep, with a 4- or 5-foot-long, light-weight wooden handle.

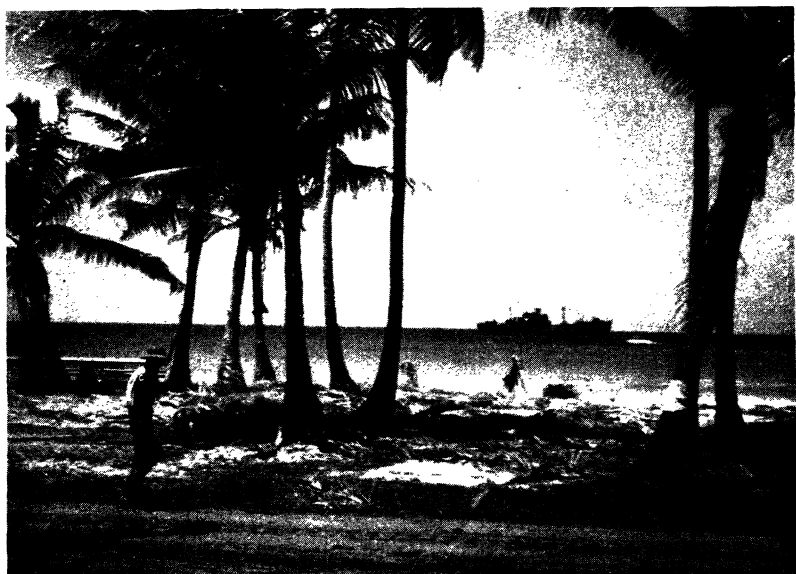
As the water-laden cloud of rotenone drifted onward for a thousand feet, it spread out, gradually becoming so diluted that it lost its effectiveness. When the water appeared as a light, tan-colored cloud, it was most effective since it retained its stupefying properties yet was not so much concentrated as to be detectable by most fishes. Sharks, apparently able to detect small amounts of the rotenone in the water, left the area until the cloud had passed. They then returned to feed on the sick and dead fish, sometimes becoming troublesome. With



PHOTOGRAPH TAKEN JULY 1, 1946, A FEW MINUTES AFTER THE ATOM BOMB EXPLODED ABOVE THE SURFACE OF BIKINI LAGOON
Note the rim of the atoll.



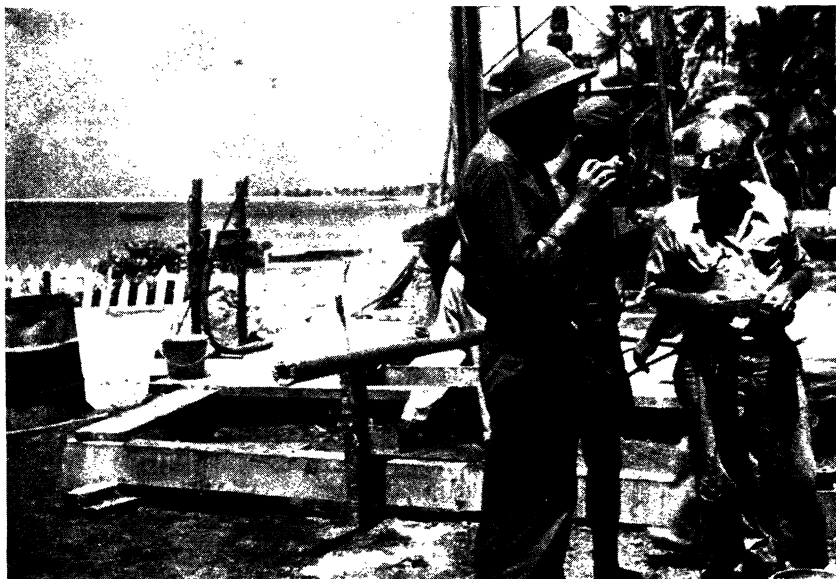
1. BIKINI ISLAND AS SEEN FROM THE LAGOON. AUGUST 1, 1947



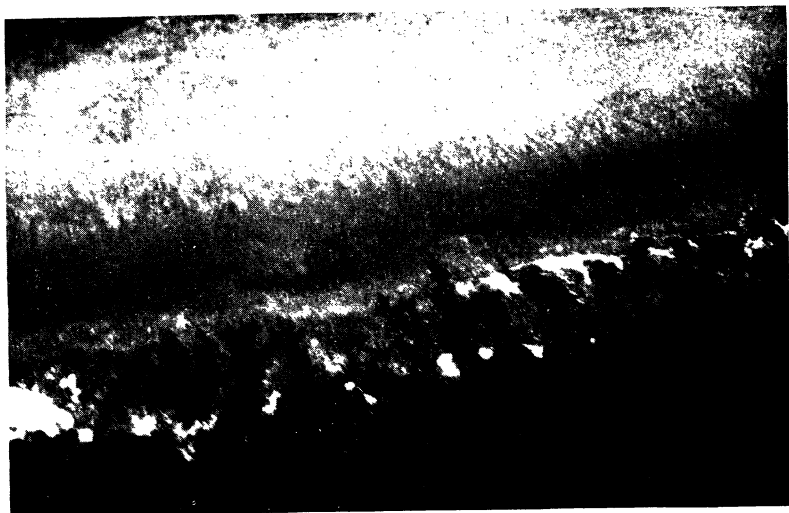
2. THE U. S. S. "CHILTON," HEADQUARTERS OF THE BIKINI SCIENTIFIC RESURVEY OF 1947, OFF BIKINI ISLAND



1. THE G. E. FAILING CO DRILLING A DEEP HOLE ON BIKINI ISLAND, 1947



2. COMMANDER ROGER REVELLE AND DR. HARRY LADD EXAMINING A FOSSIL BROUGHT UP FROM A DEEP HOLE



1. SURGE CHANNELS (DARK PATCHES IN FOREGROUND) BISECTING THE LITHOTHAMNIUM RIDGE AT OCEAN EDGE OF ATOLL RIM

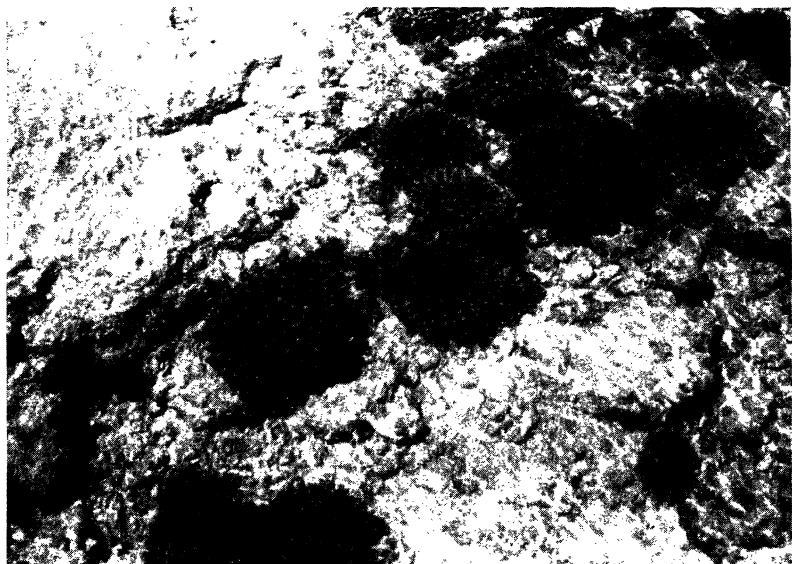


2. SAND SPIT (WHITE FOREGROUND) THAT CONNECTS WITH BOCK ISLAND ON RONGERIK ATOLL

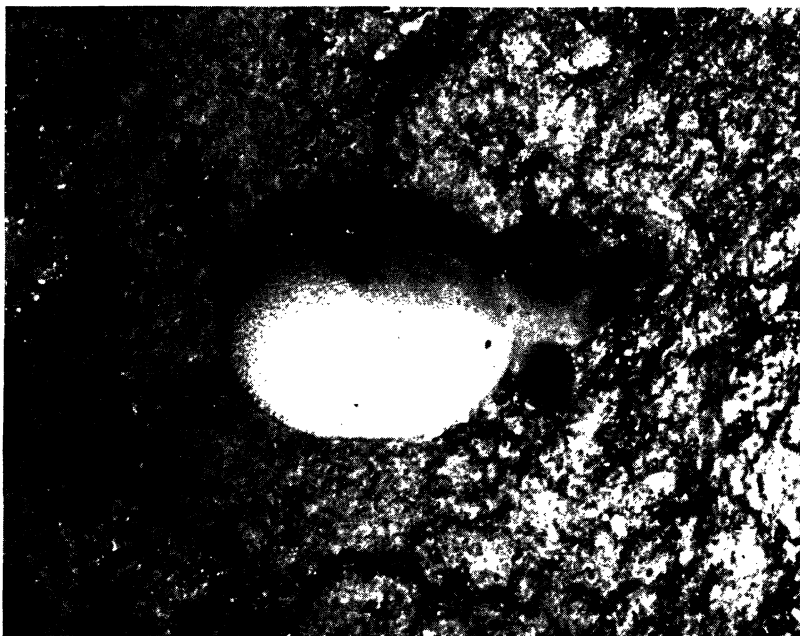
The island is covered with trees.



1. DR. ROBERT HIATT HOLDING A COCONUT CRAB TAKEN ON NANU ISLAND, BIKINI ATOLL.
AUGUST 1947

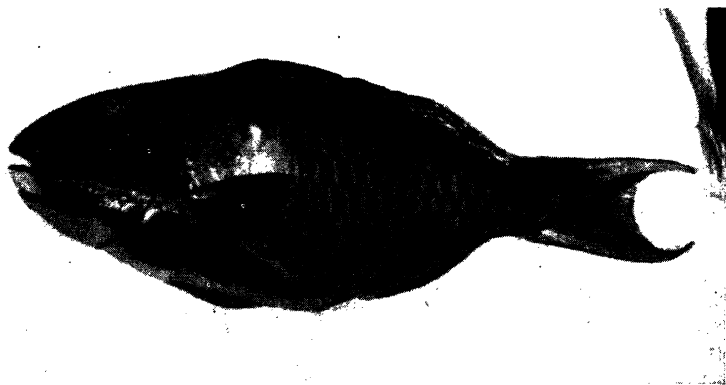


2. A SMALL SPECIES OF GOBY GUARDING EGGS AND NESTS BUILT IN THE CORAL ACROPORA
Photograph taken in July 1947.



1. THE YELLOW PUFFER

Like others of its kind, this fish inflates itself with water or air as a means of defense.



2. THE PARROT FISH

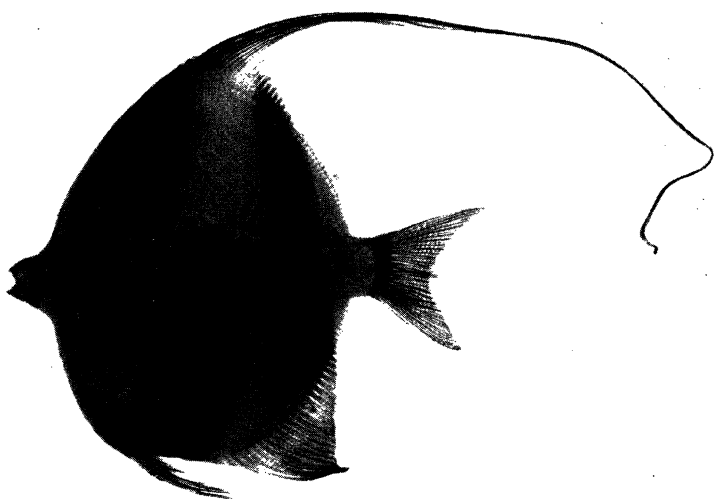
This fish, when living, is brilliantly colored with red, green, and blue.



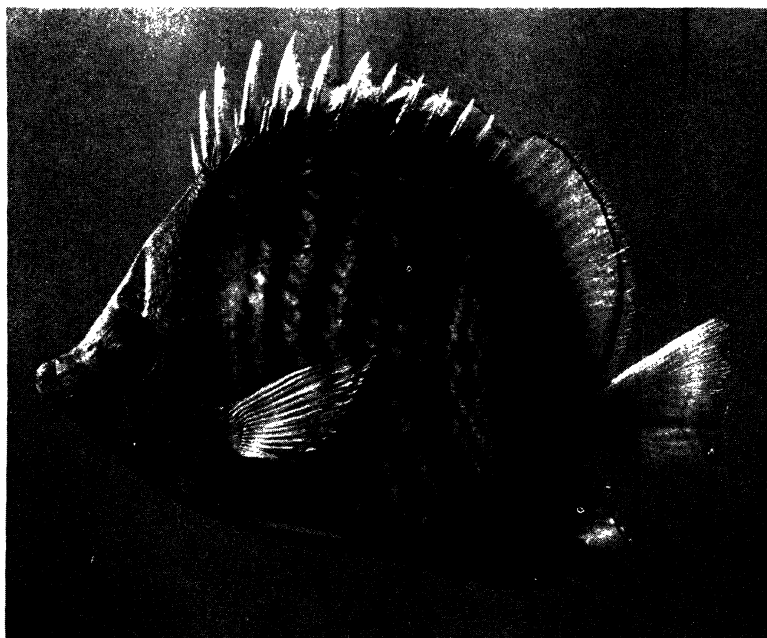
1. SURF CRASHING OVER THE LITHOTHAMNIUM RIDGE AT OCEAN EDGE OF ATOLL RIM AT BIKINI



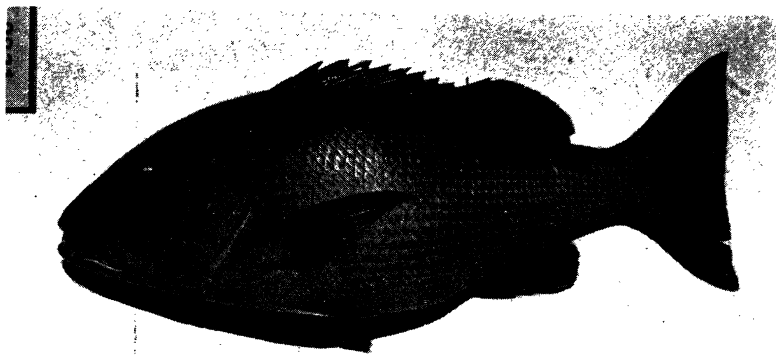
2. A GROUP OF BIKINI INHABITANTS AT RONGERIK ATOLL IN 1947



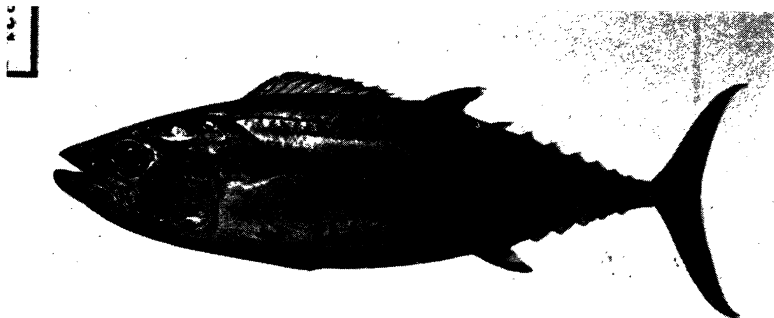
1. *ZANCLUS CANESCENS*



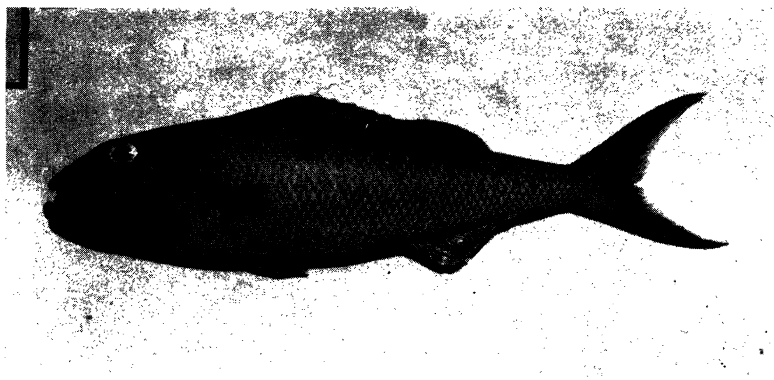
2. ONE OF THE NUMEROUS KINDS OF BUTTERFLY FISHES, *CHAETODON MERTENSIS*, TAKEN AT BIKINI



1. THE RED SNAPPER, *LUTJANUS BOHAR*



2. THE DOG-TOOTHED TUNA, *GYMNOSARDA NUDA*



3. ONE OF THE PELAGIC SNAPPERS, *APRION VIRESCENS*



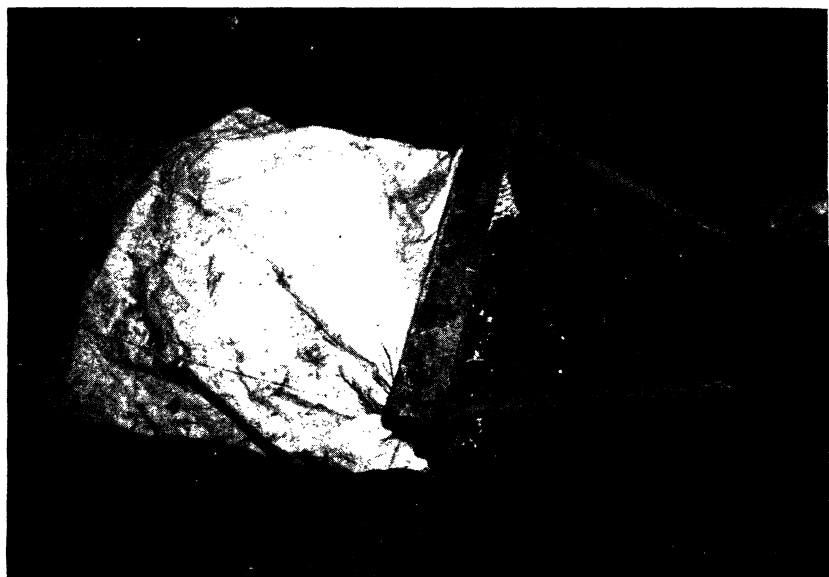
1. A VORACIOUS SHARK, *CARCHARHINUS ALBIMARGINATUS*



2. THE DEVIL RAY, *MANTA ALFREDI*



1. DR. WILLIAM R. TAYLOR, SEARCHING THROUGH A DREDGE HAUL FOR ALGAE TAKEN FROM THE BOTTOM OF BIKINI LAGOON



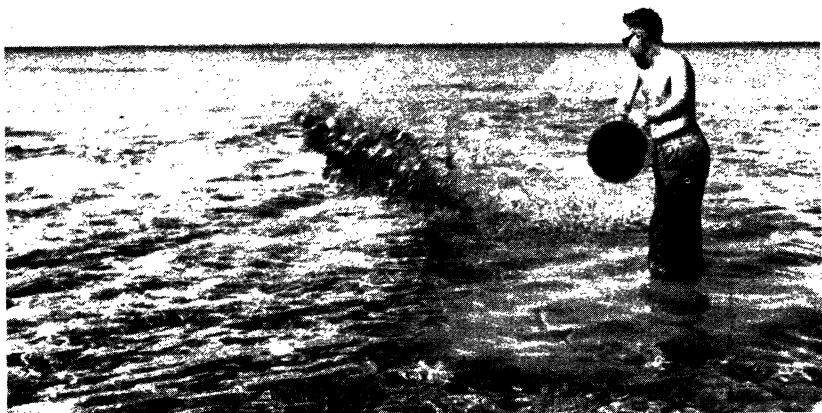
2. THE DREDGE USED FOR BOTTOM SAMPLES OF MARINE INVERTEBRATES AND ALGAE



1. ONE OF THE ICHTHYOLOGISTS FILLING A DESERT WATER BAG WITH CUBE ROOT MIXTURE JUST BEFORE GOING DOWN IN 45 FEET OF WATER TO POISON A SUBMERGED CORAL HEAD



2. THE SAME ICHTHYOLOGIST, NEARLY AN HOUR LATER, RETURNING TO THE SURFACE WITH A DIPNET CONTAINING FISH SPECIMENS



1. THE AUTHOR SPREADING THE LAST OF THE CUBÉ ROOT MIXTURE OVER A REEF IN SHALLOW WATER



2. DR. EARL S. HERALD AND THE AUTHOR RECOVERING FISH DURING A POPULATION STUDY AT BIKINI ATOLL



1. FLOATING FISH WERE RECOVERED OVER DEEP WATER BY USE OF A RUBBER BOAT



2. A LARGE CORAL BLOCK WAS USED AS A LABORATORY FOR THE PRESERVATION OF FISHES DURING LOW TIDE ON A REEF

only one or two 3- to 6-foot-long sharks feeding on the sick fish, the diver can keep watch of them. However, when two or three of these voracious creatures became too bold, as happened on one or two occasions, the ichthyologists left the water.

The searching for the demobilized fishes was done by means of a face mask covering eyes and nose, swim fins on the feet, and a dipnet. With a face mask, both hands were free to devote to picking up fishes, some of which were rather slippery. A canvas glove as an aid for holding slippery fish was used on one hand when necessary. Some of the fishes affected appeared lifeless, but when touched were found to be very much alive and quickly moved away unless caught in the dipnet. Those fishes too small to pick up with the fingers were, with a little practice, lifted from the bottom by inducing upward currents through rapid movement of the hands or feet. A fish, thus suspended for a few moments, was scooped up in the dipnet. Desirable fishes frequently swam into the crevices of the corals and erected their spines, making their removal difficult. With clear vision through the face mask, these, too, were collected.

A rubber boat, tied to one of the coral heads, served as a base from which to work and was an added safety in case someone ran into trouble under the rugged conditions under which we worked. This boat held the preserving tank, and other gear. Three good swimmers at Bikini picked up enough fish to keep one man busy preserving the specimens in the rubber boat. On shore, one ichthyologist and a Navy photographer took over 300 color pictures.

Those fishes first to be affected by the rotenone were the damsel, cardinal, butterfly, surgeon, and puffers; others such as needlefish, halfbeaks, goatfishes, gobies, jacks, threadfins, and mullets were a little slower in reacting to the treated water. The burrowing fishes, namely, eels, appeared last, probably because it took longer for the rotenone to diffuse into their habitats. Fish continued to appear for over 6 hours after treatment, and I recovered eels that came out 8 hours after the cloud had passed their burrow.

Care was exercised in picking up supposedly dead spiny fishes, and especially moray eels, since they may inflict serious wounds. Scorpion fishes, siganids, and other venomous species, even the stinging corals and jelly fishes, were treated with respect.

The snake eels often appeared with about 6 to 12 inches of their head section above the bottom. I grabbed them firmly and quickly, then pulled out the remaining 2 or 3 feet of their bodies. A light touch or a miss when grabbed usually caused the eel to withdraw into its burrow, and the specimen was lost.

The rotenone appeared to affect the fishes by constricting the capillaries of the gills, depriving the animals of an adequate oxygen sup-

ply. They left their hiding places for more oxygen, thus exposing themselves under a weakened condition and simplifying their capture.

Shallow tidal pools that trap fish at low tide are simple to work, but the use of rotenone in the ocean surf on the ocean reef of a coral atoll requires special technique.

Rotenone was used successfully along the lithothamnium ridge in the ocean surf. The "mud" was administered a few minutes after the low point of the tidal cycle. An area was selected where pools occurred but which were not completely connected with the surge channels. These pools were desirable as settling basins for the sick and dying fishes. The area between two or three surge channels, where the waves flow inward across the ridge was the place where we placed the rotenone mixture. Big handfuls of the thick mud were thrown out as far as possible into the backwash of a wave. The next moment the oncoming breaker churned the water into foam and carried the water-laden cloud of rotenone inward, spreading it over the area and into the numerous crevices; then it flowed out the surge channels. Soon the rotenone cloud was distributed along the ocean edge of the reef, and some was brought back again over the lithothamnium ridge. The continual surging inward of the water brought in the sick fish. Men were stationed along the surge channels to take fishes that were being swept out to sea and perhaps lost. After the pools and channels cleared, the bottoms were searched for fishes by the skin divers.

The use of a face mask in skin diving and swimming enables one to see clearly for 50 to 100 feet in the lagoon and ocean waters. Looking down in the surge channels between the corals, one sees a gorgeous display, a colorful marine garden of coral algae and fishes. Some of the corals are fan-shaped, others resemble the antlers of deer. They are blue, bright green, red, brown, yellow, and purple, contrasting with the white foraminiferal sand of the bottom.

The light from the tropical sun flickers down into these enchanted caverns, filled with the blue sea. The trembling shafts of light illuminate the green, brown, and red algae, waving in the dim light. Fantastically shaped fishes, as if from another world, dart about, reflecting their weird color combinations of brilliant blues and sapphires, greens, and yellows, red or scarlet, and with black and white markings contrasting sharply. Some have big red spots, others sapphire-blue bars and dazzling yellow and crimson stripes.

Butterfly, damsel, surgeon fishes and wrasse lazily swim about in the aquatic caverns and channels, but the moment a large predaceous fish appears they seek protection, disappearing there, reappearing here, among the coral growths. Some swim as easily sideways and upside down as in a vertical position. The view of this gorgeous marine garden fades away into nothingness a hundred feet or more below.

DEEP-WATER USE OF ROTENONE

Vernon E. Brock and Dr. Earl S. Herald, two ichthyologists who are excellent swimmers and skin divers, successfully carried on several deep-water poisonings of fishes with powdered cube root. They mixed in the usual manner about 35 pounds of the substance, then placed 5 to 10 pounds of the "mud" in desert water bags. Equipped with standard U. S. Navy shallow-water diving outfits, Brock and Herald took the rotenone to the bottom, distributing it around coral growths. Down below with the usual dipnets, they recovered fishes, bringing them to a man at the surface, who preserved the specimens. This deep-water work was necessary to obtain a more complete picture of the fish fauna of Bikini and the change in kinds of fishes at various depths in the lagoon. Several fish species occurring over the shallower parts of the reefs normally are not found at depths below 10 or 20 feet, whereas some kinds below that depth are not taken near the surface.

COLLECTING WITH A LIGHT AT NIGHT

A bright light suspended from a small ship at night at the surface of the sea attracts to it myriads of nocturnal organisms—crustaceans, worms, squid, octopi, and numerous species of fishes. Silversides, small wrasse, round herring, the pelagic stages of goatfishes, surgeon fishes, puffers, lizard and file fishes dart in and out of the field of illumination. Large flying fishes, a foot or two long, come swimming or flying toward the light at night. Down below a few feet, larger predaceous fishes can be seen rushing about feeding on the abundant animal life. Eager collectors gathered above this light on a platform, and with fine-meshed dipnets scooped up the animals, preserving them for future study.

Several kinds of fishes and invertebrates taken around the light were never collected by any other means at Bikini.

UNDERWATER TELEVISION

At Bikini in 1947 I saw demonstrated the Navy's new underwater television, prepared and operated by the Cornell Aeronautical Laboratory, Buffalo, N. Y. The camera end of this remarkable devise was set up on the deck of the sunken submarine, *Apogon*, in 160 feet of water. It was sufficiently sensitive to daylight to give clear and precise images on the screen in the control and observation room of the U. S. S. *Coucal*. The color patterns of fishes were portrayed in pale greenish light with distinctness as they swam in front of the lens. I identified with ease two species of pigfish (*Lethrinus*), the trumpet fish (*Fistularia*), a jack (*Caranx*), the moorish idol (*Zanclus*), and *Siganus punctatus*.

This apparatus opens up new fields of investigation in the study of aquatic animals in their natural habitats. Scientists and laymen who wish to study animal behavior will be able to do so now without the dangers of deep-water diving. The applications of underwater television to biological research is of the same magnitude of importance as the discovery and first use of the microscope.

BIKINI'S BIOLOGY, PAST AND FUTURE

Bikini's ecology was disturbed, not only through the atom bomb explosions, but by the presence during the Crossroads Operation of a great armada of ships, with about 45,000 men, dumping garbage and debris into the lagoon waters. This, together with the blasting of coral heads in preparation for the great anchorage, made the water turbid and increased the sedimentation in certain areas. During March and April 1946, corals could be seen at a depth of 120 feet at midday, but during July of both 1946 and 1947 coral heads were scarcely visible at depths of 35 feet off Bikini Island. These changes appear to have been confined to the eastern and northern reefs off Bikini Island in the lagoon, whereas the southern and western reefs showed little change. The water there was as clear as in the early part of 1946.

Open ocean waters are relatively barren. Organic matter and dissolved nutriments in the sea are very slight. An atoll, however, is a very rich area of living plants and organisms. It is an oasis in an aquatic desert. Its reefs support luxuriant growths of algae, coral, and vast numbers of animals. This richness results from the conservation of organic matter by the living forms.

Organic matter is not lost in the complicated food chains of the living organisms. They may die in the lagoon waters, but are immediately devoured by the scavengers—crabs, lobsters, shellfish, fishes, worms, coelenterates, and echinoderms—which in turn are eaten by predaceous animals. Plant life is consumed by the vegetable-eating fishes and other creatures. Coral polyps are fed upon by certain file fishes, whereas parrot fishes scrape algae off the corals. Even through the death of a 10-ton shark or manta ray, the organic matter is not lost. It appears in the form of tiny organisms such as bacteria, worms, and crustaceans. These in turn form the plankton—the chief food of numerous fishes. Thus the atoll becomes a great storehouse or reservoir of living organisms competing for every bit of nourishment.

The aquatic plants extract carbon dioxide from the sea water. Both plants and animals deposit calcium carbonate in building their calcareous skeletons, which remain after death. The organic matter is re-used by the living, and the skeletons of the dead remain to build

up the solid rocky atoll, leaving scarcely a trace of the animal proteins in the limestone reefs or in the bottom deposits of the lagoon floor.

The antiquity of such an isolated atoll must be very great to have accumulated through the eons of time such a tremendous variety of animals and plants—to have deposited nearly two miles of animal and plant remains on top of a volcanic mountain top.

The distribution of this great variety of animal life that now lives at Bikini and on other isolated atolls must have been accomplished through pelagic stages—free-floating eggs and larvae—across vast stretches of the open ocean. Fishes that build nests in the corals and are without such a means of dispersal from one atoll to another, or from island group to island group, have in many instances differentiated sufficiently from their neighboring allies to be recognized as distinct species. Those with pelagic stages usually are distributed extensively, some ranging from Easter Island to the Red Sea. There apparently has been enough interchange of individuals to keep each of these widely ranging forms breeding as a single species.

That Bikini and the northern Marshall Islands have some endemic species of fishes is highly probable. Our recent ichthyological investigations indicate that in about one-third of the fish families studied, one or two new or previously unknown species occur. These are being described along with every other kind of fish from Bikini, and the publication of this material should make it possible to detect in the future any anatomical changes that might be induced by the Crossroads experiments.

The mystery of the biological changes resulting from radiation are little known. In that great natural laboratory, they are difficult to observe and more difficult to measure. The time is too short since Able and Baker Days for the radiation to have caused observable anatomical changes in the animals, if any have occurred. Undoubtedly, alpha, beta, and gamma rays will be emitted for years to come, and how those rays will affect the somatic and genetic cells of the organisms at Bikini is yet to be discovered. Undoubtedly there has been and will be sterilization of sex cells and the destruction of red blood cells, neoplastic growths may form, and possibly mutations will appear.

Any organism that changes morphologically to any extent may not be adapted to compete in the continuous struggle for existence, or if weakened by the fission products, may have little chance of survival in the keen competition that exists. These unfit animals soon form part of the food chain in the intense struggle of life. The carnivorous fishes, feeding on the algal eaters that fed on contaminated algae, are in turn exposed to the isotopes and their radiations. Thus, during the course of a few years, nearly every lagoon fish may be expected to have been subjected to the radiation effects, at least in a small way, of the atomic bomb.

Undoubtedly, countless animal individuals have perished at Bikini because of the atomic bomb experiments and still others may perish. But this destruction of life in a large atoll like Bikini amounts to only an extremely small percentage of the total animal life. The overall picture of life on the reefs has changed little because beneath this surface layer, and from extensive adjoining unaffected areas, individuals have come forth to repopulate and occupy the reefs. The pressure of population from all sides into the damaged areas is very great and soon replaces the losses. Thus nature begins the repopulation cycle, and, if given sufficient time, the wounded reefs will be cleansed of their contamination, biological equilibrium will be reached, and life will establish itself as in past millenniums—similar to that before man released the greatest destructive force in his history.

THE SENSES OF BATS¹

BY BRIAN VESEY-FITZGERALD, F. L. S.

[With 4 plates]

Of all the many problems which bats set for the inquiring naturalist, none has been more puzzling than that presented by their flight at night: the way in which they catch the insects upon which most of them feed (in the case of British bats, upon which all of them feed) without colliding with objects in their path. The flight of bats is rapid and the course erratic, frequently through thick woods or the narrow winding passages of caves, often in total darkness. It has always seemed unlikely that animals with such small eyes could see well enough in the dark to fly in such surroundings without mishap. Many experiments have been tried with captive bats to demonstrate their ability to avoid obstacles which they could not see. Toward the end of the eighteenth century the Italian scientist, Lazzaro Spallanzani, found that bats which he had blinded could fly about a room, avoiding the walls, the furniture, and silken threads stretched across their path. A Swiss scientist, Louis Jurine, confirmed this and made the additional discovery that bats lost their ability to avoid obstacles when their hearing was interfered with. Cuvier poured scorn on these findings, and they were forgotten for a century and a half. All that was remembered was that a blinded bat could fly perfectly surely. But the uncanny ability remained, and all sorts of theories were advanced to account for it. It was suggested, for example, that bats were very sensitive to changes in atmospheric pressure.

Then, in 1920, Professor Hartridge suggested that bats when flying in the dark were probably able to ascertain the position of obstacles by means of supersonic sounds emitted by the animals and reflected to their ears. Twenty years later, after the development of radar as an operational system, Griffin and Galambos working in America were able to prove him correct.

Both radar and sonar are, of course, founded on the same fact, namely, that if a short burst of energy is sent out and the time taken for the echo to come back is noted, then, if the speed at which the energy travels is known, the distance of the object can be accurately calculated. Moreover, by sending the energy down a narrow beam

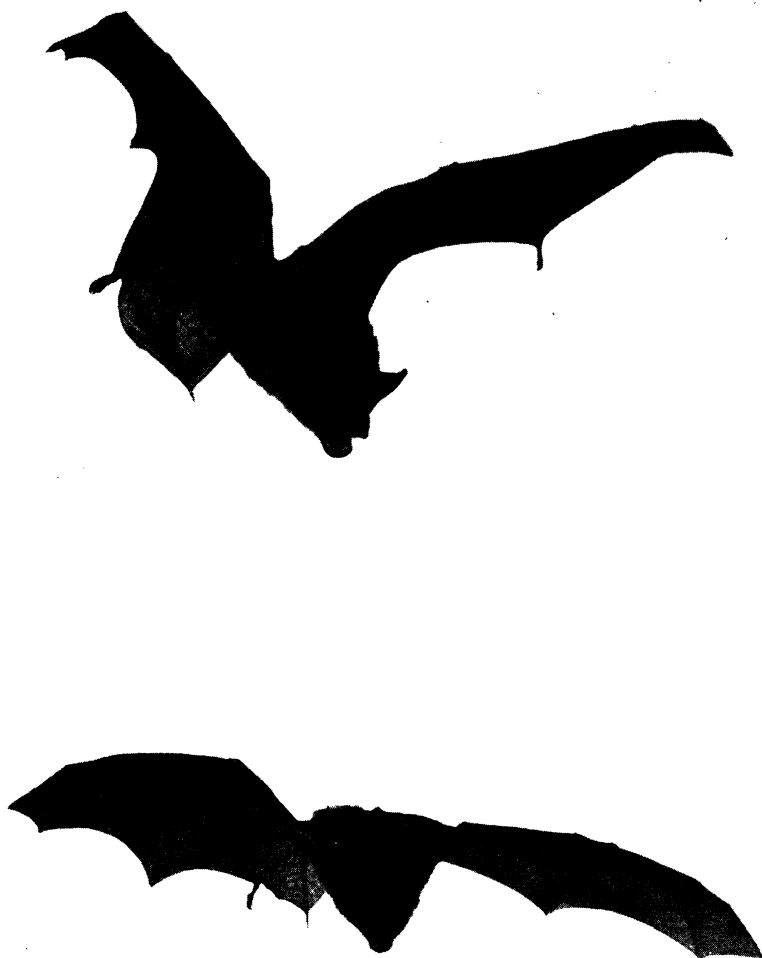
¹ Reprinted by permission from *Endeavour*, vol. 6, No. 21, London, January 1947.

the bearing of the object can be accurately determined. In radar the energy used is in the form of electromagnetic waves; in sonar (the method by which the depth of water is measured) ordinary sound waves are used. In their direction-finding bats use not audible sound waves, but, as Hartridge suggested and as Griffin and Galambos have proved, supersonic waves. The range of frequencies that a normal human being can hear is from about 16 vibrations a second to about 30,000 a second. Middle C is 256 vibrations a second. The range of frequency of the supersonic waves used by bats is from about 25,000 to 70,000 a second, and is thus mostly above the limit of human hearing.

Griffin and Galambos began their work by confirming that blindfolded bats are able to fly surely. They then confirmed Jurine's discovery that if the hearing of a bat is impaired it is unable to avoid obstacles when flying. Indeed, they found that a bat with both ears covered is most reluctant to take wing at all, but that a bat with one ear covered will fly with moderate success, though it will be unable to avoid all obstacles. These simple experiments indicated that bats are made aware of the position of obstacles which they cannot see by means of sound waves reflected from them. They then covered the noses and mouths of their bats, but left the ears uncovered, and found that again the animals were unable to fly with certainty. They thus proved that the sound waves reflected by objects must be produced by the vocal apparatus of the bats themselves.

Their further experiments were conducted with the aid of an electronic apparatus known as a supersonic analyzer. This consists essentially of a microphone sensitive to supersonic vibrations, a magnifier which amplifies them and converts them to vibrations of a lower frequency, and a recorder which traces a graph on paper when supersonic sounds are received. The analyzer measures the frequency of any supersonic vibrations it may pick up. By means of this instrument it was discovered that bats make supersonic sounds at frequent intervals almost all the time. The frequency of the vibrations varies, of course, but it is most usually about 50,000 a second, and at this pitch each squeak lasts for a little less than one two-hundredth of a second.

Now, it is evident that the more frequently squeaks are emitted the fuller the information received. It has been proved that a bat at rest emits a supersonic squeak about 10 times a second, but that as soon as it takes wing the rate goes up to about 30 a second. That was to be expected, since a bat on the wing obviously needs more information than a bat at rest. Griffin and Galambos further found that the closer a bat approached an obstacle the faster became the rate of squeaks, rising to 50 and sometimes even to 60 a second, and dropping to normal as soon as the obstacle was passed. The rate of squeak is, of course, governed by the distance from the object, for there must be time for the echo to come back before the next squeak is sent out.



THE WING ACTION OF A BAT IN MORE OR LESS LEVEL FLIGHT AND FLYING TOWARD THE
CAMERA

Bats make between 15 and 20 strokes of the wing a second, and fly at about 10 miles an hour. (See also
pl. 2, fig. 1.)



1. THE WING ACTION OF A BAT IN MORE OR LESS LEVEL FLIGHT AND FLYING TOWARD THE CAMERA
(See also pl. 1.)

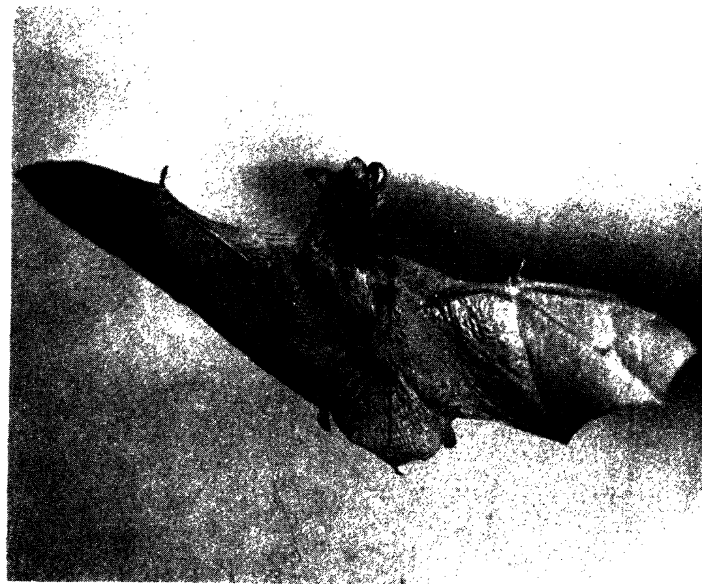


2. FLIGHT MORE OR LESS BROADSIDE TO THE CAMERA
(See also pl. 3)



FLIGHT MORE OR LESS BROADSIDE TO THE CAMERA

Bats fly by raising the wings partly folded, bringing them sharply down and forward. Note that in these photographs the mouth is held open. (See also pl. 2, fig. 2.)



1. WARNED BY THE ECHO, A BAT BANKS SHARPLY TO AVOID A WALL.
How close it has come without accident is shown by the shadow.



2. SWOOPING TO ALIGHT

Note the depressed interfemoral membrane. All these photographs were taken at $1/100,000$ second.

The supersonic tone is not the only sound produced by bats. In addition to the supersonic squeak, which cannot be heard by human beings, they produce three other kinds of sound: (1) The ordinary voice, which is the flight call, and which Hartridge has named the signaling tone; (2) a buzz, which is audible if one is quite close to the animal; and (3) a click, which is usually audible at a distance of several feet. I am not competent to say whether the buzz differs in any way with the species; it sounds exactly the same to me whether emitted by a serotine (*Eptesicus serotinus*) or a pipistrelle (*Pipistrellus pipistrellus*), nor can I distinguish any difference between the clicks emitted by the different species. The flight calls, however, are quite distinct. It is possible to distinguish between the species on the wing by means of their flight calls (it is also possible with practice to distinguish between the types of flight), and I have elsewhere attempted to translate the differences between the calls of the various species to paper. It has been shown that the buzz and the click are accompanied by the supersonic tone. In the case of the click there is a single short burst of supersonic energy, but in the case of the buzz there is a continuous evolution of the interrupted supersonic tone. The flight call, however, may be produced by itself or it may be accompanied by the supersonic tone. Some bats, notably the lesser horseshoe (*Rhinolophus hipposideros*), have a considerable vocabulary of ordinary sounds, whereas others, notably the whiskered (*Myotis mystacinus*), scarcely ever make a sound of this sort. I have never heard the whiskered utter a sound on the wing, and of the many I have kept in captivity only a few have uttered faint grunts, and those very occasionally, when at rest.

How these four different types of sound are produced is not yet clear, but examination of the vocal organs of bats shows that they are very different from those of other animals. The larynx, which in most animals is built of cartilage, in bats is made of bone and is comparatively a massive structure with large and powerful muscles. The strength of the bat's larynx and its small size are obviously well adapted to the production of supersonic sounds, for there must be tremendous energy in the supersonic squeaks as compared with the audible squeaks. The higher the note and the greater the frequency, the greater the energy.

Though it is not yet known exactly how the supersonic vibrations are produced, it is known how the bat avoids hearing the squeak. It is, of course, essential that only the echo should be heard by the bat. The same difficulty had to be overcome in radar transmission. In order to ensure that only the echo is picked up by the receiver, this is suppressed while the transmitter sends. Something of the same kind happens in the bat when emitting the supersonic tone. Griffin and Galambos found that while the squeak is being made a muscle in the

ear contracts momentarily, shutting off the squeak, and permitting only the echo to be heard.

Bats are not the only creatures with the power of echo-location. The tapping of Blind Pew's stick is an example of the same process, and many blind human beings develop what appears to be an uncanny ability to move about without striking obstacles. Nor are bats the only creatures able to hear supersonic vibrations: dogs, for example, are often trained on the Galton whistle. But so far as is known at present bats are the only creatures that emit supersonic vibrations and guide themselves by the reflections. This important discovery, however, still leaves unanswered many questions about the behavior of bats, and, as is the way with important discoveries, poses a number of fresh problems.

Invariably the first question that is asked is: Why do not the bats become confused between the echoes from their own squeaks and the echoes from the squeaks of their neighbors? It might be thought that with a large number of bats of the same species together in a cave or in the roof of a church, and all uttering supersonic squeaks, confusion would be inevitable. But it must be remembered that supersonic squeaks do not travel far, for their energy is quickly dissipated in the air. It has been shown that the supersonic squeaks of bats travel only about 15 feet, and that they are able to give a useful echo only up to about 12 feet. In other words, provided that the bats are not crammed close together, there is very little likelihood of confusion. But, as everyone with any field experience of bats knows, they very often are crammed close together, yet there is no confusion. It seems evident that there is a difference in the frequency of the vibrations made by each bat. A very slight difference in frequency would be sufficient to enable each bat to recognize its own voice.

There remain a number of problems to which no answer has yet been given. First, do bats emit the supersonic squeak through the mouth or the nose, or both? All the British bats are insect eaters, and all, with the possible exception of the barbastelle (*Barbastella barbastellus*), habitually fly with their mouths open. Furthermore, all the British bats capture their prey while in flight, and most of them take flying insects. What happens when the bat closes its mouth on catching an insect? Does echo-location cease (in which case the bat must fly blind) or does it continue through the nose? We do not know. In the greater horseshoe (*Rhinolophus ferrum-equinum insulans*) the epiglottis does not open into the back of the mouth as in most animals, but is projected up into the roof of the mouth, fitting into the rear opening of the nasal passages. It is not fixed in this position, and can probably be withdrawn, but the arrangement suggests that the supersonic squeaks, in the Rhinolophidae at any rate, are emitted through the nose, and this suggestion receives additional

support from the extraordinary skin development on the muzzles of these bats. While the purpose of this appendage, which in some species attains an astonishing complexity, is not known, it has been suggested that it is concerned with directing the squeak into a narrow beam so that the bat's knowledge of its position is greatly increased. Be that as it may, I have no doubt from long personal observation that the horseshoes have a much finer appreciation of position than other British bats, and especially is this so in the case of the greater horseshoe. Indeed, this species is quite uncanny in its judgment of distance. Bats normally hang head downward, suspended by the toes. It is the usual practice for bats to land head upward and then to shuffle round until they can get a grip with the toes, but the greater horseshoe is accustomed to turning a somersault in the air and gripping straight-way with the toes, landing, in other words, in the head-downward position. Very rarely indeed have I seen a bat miss its hold, and there appears to be no slackening of speed as the resting-place is approached. Some of my captive greater horseshoes used to sleep under a sideboard, and when they were hanging there was little more than a couple of inches clearance from the floor, yet they would fly under the sideboard, turn their somersaults with absolute certainty, and hang by the toes. And many, many times have I watched this acrobatic performance when they have been hanging from picture rails and so forth.

There is a marked difference in the structure of the ear in the Rhinolophidae and in the Vespertilionidae. In the former the pinna is comparatively simple in build, but in the bats without nose-leaves the ear is a much more complex structure, characterized by a great development of a lobe known as the tragus. This is especially well seen in the long-eared (*Plecotus auritus*), in which species it stands up like a second pinna. It has been suggested that the tragus is in some way connected with echo-location, and the fact that the bats with nose-leaves have no tragus while the bats with the tragus have no nose-leaves is surely significant. It would appear that the two developments must in some way perform similar functions.

It is, I think, noteworthy that the long-eared, in which there is such a marked development of the tragus, is in comparison with other bats of the same group a master of flight in confined quarters. Most bats, when flying to their feeding grounds, do so at a considerable height; the long-eared does so very close to the ground, often at a height of no more than a few inches, and the flight is fast, direct, and confident. Furthermore, the long-eared captures comparatively few insects in flight, preferring to pick them off the leaves of bushes and trees, a habit which entails the nicest judgment of distance.

Two other British bats, Natterer's (*Myotis nattereri*) and the whiskered (*M. mystacinus*), have the habit of picking their prey

from foliage rather than taking it in flight. Natterer's is fairly impartial, but the whiskered very rarely captures a flying insect, preferring to search the hedgerows and fences, especially for spiders, of which it is inordinately fond. Both species have a well-developed tragus, and in both, but more particularly in Natterer's, there is a marked development of the glandular pads on the face.

How bats find their prey is a mystery that has not yet been solved. It is certain that they cannot find it by sight, and there does not seem to be any evidence that their powers of scent are particularly acute. How, then, does the noctule (*Nyctalus noctula*), flying high and fast, find its prey? If you throw a pebble into the air beneath a hawking noctule, the bat will dive on to it, swerving away from it at the very last moment without touching it. Attach a fly to a long line and make casts into the air while bats are hawking and you will have them diving at the fly, but it is very unlikely that you will catch one. Daubenton's bat (*Myotis daubentonii*) is sometimes caught on the flies of anglers, but almost always by the wing. I do not think that there has been a single instance of the bat being caught by the mouth, which suggests that at the last moment (but too late to avoid contact altogether) it has realized its mistake. All this suggests that the supersonic squeak sends back an echo from anything flying into or across the path, but it does not explain how the bat knows that that something is worth investigating. Yet I have never seen one bat dive at another, even when there have been many flying at random in a confined area. Nor does it explain how the long-eared and the whiskered know that there is an insect or a spider on what their echo-location must have told them is an obstacle to avoid. Yet in a long experience of whiskered bats, I have not seen one hit a fence or make fruitless visits along a hedge.

One would be inclined to say that the supersonic tone was even more selective than we know it to be were it not for certain things that field experience has brought to notice. I have seen bats of different species collide in mid-air—on one occasion a noctule with a serotine (and both animals were killed), and on another occasion a pipistrelle with a barbastelle (when the pipistrelle was killed). These accidents happened during the evening hawking, and one can only suppose that at the time echo-location had stopped, possibly because both animals had captured insects and their mouths were closed.

Field experience shows too that there are times when echo-location does not function at all. I have caught many bats by netting their dens of a summer night. At one time, anxious to discover whether bats flew at night or not—it was at that time thought that they had an evening and a morning flight only—I made a number of all-night watches at dens of noctule, whiskered, pipistrelle, serotine, and Natter-

er's, and, after the bats had left the hole for the evening flight, netted the entrance. I caught many bats (and at almost all hours of the night) in the nets, trying to get back to the holes. At that time nothing was known about supersonic vibrations in connection with bats, and I did not think that there was anything odd about it. But in the summer of 1946, realizing that the supersonic tone should have warned them of an obstruction, I repeated the process at dens of noctule, whiskered, Daubenton's, and serotine, with the same result. The bats appeared to be quite unaware that there was an obstruction and flew straight into the nets. Later I covered the entrance hole to a noctule den with thick brown paper, and even this did not seem to be indicated to the bats, which flew straight into it. Before returning to their den noctules fly around the tree and in and out among the branches with never a false movement, yet they are unaware of an obstruction at the very entrance to their sleeping quarters. It seems evident that echo-location, for some reason, is shut off at that moment.

On the other hand, it seems to operate to some extent during hibernation. Everyone who has entered a hibernaculum of bats must have noticed the tremor that goes through the sleeping creatures at the first presence of a stranger. They are asleep, and incapable of movement, but there can be no doubt at all that they are aware.

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MOLLUSKS AND MEDICINE IN WORLD WAR II

By R. TUCKER ABBOTT
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[With 3 plates]

When American troops of MacArthur's Sixth Army landed on the eastern shores of Leyte Island to begin the liberation of the Philippine Islands, they were committing themselves not only to a bitter military struggle but also to one of the strangest of the many medical battles of the Pacific campaign. Within a week our troops had fanned out over an area which is highly infectious with a fatal snail fever or blood-fluke disease known at that time to only a comparatively small number of tropical-disease experts. Up through Gloucester, Finschhafen, and Hollandia many of the men had come, fighting Japs with a rifle in one hand, warding off malaria with a yellow atabrine pill in the other. Here on Leyte the malaria mosquito was almost unknown, but in its place was a tiny fresh-water snail carrying and spreading a parasitic disease which, if left untreated, led to extreme enlargement of the liver, and usually ended in the death of the victim.

Characteristically, the disease did not manifest itself among the troops for a number of weeks. Then on New Years Day at an evacuation hospital in the town of Palo the first 2 military cases were discovered. An intensive survey of our personnel was immediately begun, and the fears of the Army doctors were confirmed by the discovery of 973 cases. Before the epidemic could be brought under control, over 1,700 Army and 17 Navy men had been stricken by the blood-fluke disease, schistosomiasis.

NATURE OF THE DISEASE

"Schisto," as the disease became familiarly known among the troops, is caused by a parasitic trematode worm which lodges itself in the blood vessels of the liver and the mesenteric vessels of the mammalian host. The adult male is about a half inch in length with a large groove along its underside in which the slender and slightly longer female rests during most of her mature life. Each fluke has two round suckers at

the head end, one for holding to the walls of the blood vessel, the other for ingesting blood cells. The greatest damage to the host, however, does not come from the small loss of blood or the obstruction caused by the worm, but rather from the vast number of tiny, spined eggs being constantly liberated by the female. A large proportion of the eggs are carried to the liver by the blood stream, and as protective encystment takes place, hepatic congestion or liver blockage develops. Ultimately, with increasing deposition of eggs and the introduction of toxins given off by the adult flukes, the liver becomes a gigantic mass of scar tissue. Accompanying symptoms are daily fever, extreme weakness, diarrhea, loss of appetite and weight, emaciation, and, in untreated cases, death from exhaustion.

A number of the eggs laid by females in the mesenteric blood vessels work themselves through the intestinal wall and pass out into the open, thus permitting the life cycle of the worm to continue. The eggs must reach fresh water directly or be rain-washed within a day or so to a nearby creek. There, the eggs break open to liberate a minute, free-swimming miracidium. Unless this microscopic larval form can reach an *Oncomelania* snail within 35 hours it will die. The miracidium will swim rapidly through the water in erratic and undirected courses until by chance it passes within a few inches of an *Oncomelania* snail. At that moment, it turns and takes a straight course to the mollusk and plunges its head into the flesh of the snail. In a matter of a few minutes it will have bored itself through the skin. In time, the tiny invader burrows to the liverlike digestive gland of the snail, and there, during 8 weeks of complicated transformation, multiplies into hundreds of small, fork-tailed cercariae. The more miracidia that invade a single snail, the greater will be the production of cercariae; in heavy infections, the reproductive ability of the molluscan host will be impaired.

It was this fork-tailed cercaria that infected our troops. During the early hours of morning thousands are shed from the ruptured tissues of the *Oncomelania* snails. Invisible to the naked eye, they lie on the quiet surface of the creeks and marsh waters and await the first person that comes to bathe or swim. Cercarial penetration of the skin is painless and often goes unnoticed, although occasionally in heavy infections an itchy rash or cercarial dermatitis is produced.

Two to three months may pass before the victim shows any distressing symptoms of the disease. During this incubation period the larval worms will have migrated from the small blood vessels and lymphatics to the heart through the venous system and will have reached the lungs. From here, the maturing worms penetrate through the tissues to the vessels near the liver, pair up in sexes, and begin their deadly production of eggs.

CAMPAIGN AGAINST THE DISEASE

Fortunately, two medical units capable of temporarily coping with the menace were stationed on Leyte Island when the schistosomiasis outbreak occurred. Combined medical guns were opened on the problem by the Fifth Malaria Survey Detachment under Maj. M. S. Ferguson and the Army Medical Research Unit under Maj. F. B. Bang. Both officers were on military leave from the Rockefeller Institute for Medical Research. The method of treatment for the disease by the injection of an antimony drug called fuadin had been rather well worked out by previous workers, so that the immediate and most important problem became one of preventive medicine—how to keep our men from catching the disease. This involved a laborious survey of military personnel and natives in the endemic area, a search for waters inhabited by the deadly snail, and the introduction of a rigorous educational program among the troops. Signs blossomed out over the entire area wherever infectious waters were located. Slogans of “Danger! Snail fever! Keep out of this river,” “Schisto and death here! Don’t swim in these waters,” became the roadside counterpart to the “Come to Smith’s Beach. Excellent swimming” billboards at home.

The Army and Navy, however, were as much interested in a thorough research attack on the problem as they were in an immediate solution of the Leyte situation. They wanted to be prepared for similar epidemics if and when we sent troops into the highly endemic areas of China’s Yangtze Valley and the Japanese home islands. The Army sent out to the Philippines, and later Japan, the Commission on Schistosomiasis, headed at first by Dr. Ernest Carroll Faust, schistosomiasis specialist, and later under the direction of Dr. Williard H. Wright, expert on public health matters and chief of the Division of Tropical Diseases at the National Institute of Health. From Commodore Thomas Rivers’ unit on Guam, the Navy dispatched two doctors and a snail specialist. The use of the latter, a mollusk man, represented the first time that a military organization had employed a malacologist for snail research.

Long after the last of the schistosomiasis cases among our men had been reported and successfully treated, this group of scientists were continuing their research. The Army group went on to Japan and the Navy team was sent into China. Our knowledge of the distribution, habits, life cycle, methods of survey and identification, and control of the schisto-carrying snail was increased tenfold. Successful repellents and protective clothing were developed. Substantial advancements were made in chemotherapy and methods of surveying for the disease.

ROLE OF THE SNAIL

The key to lasting preventive measures against the blood-fluke disease is the elimination of the mollusk, for without this one kind of snail the disease could not continue to exist. Of the several hundred species of fresh-water mollusks living in the Philippines, only the *Oncomelania* snail has been known to serve as the intermediate host. Although this species of mollusk is always found in endemic areas, there are localities where the disease is unknown, yet where the snail is present. One such region discovered by the Navy exists in the Lake Lanao area of central Mindanao Island. Formerly an American military site, and perhaps in the future to be used as a Philippine Army training camp, the country bordering the north end of the lake is cool, relatively free from tropical diseases, and not unlike the countryside of Connecticut. Yet the tiny creeks flowing into the northeastern end of the lake are heavily colonized by *Oncomelania* snails. Until these snails are eliminated, the area must be considered a potential breeding ground for the blood fluke. It is probably only a matter of time before the disease is introduced and established there.

Surveying Philippine jungles and swamps for *Oncomelania* snails was, before the war, a particularly difficult task as is evidenced by the fact that Philippine workers, familiar with the country, found the snail in only 25 percent of localities where the disease was endemic. Recognition of the disease-carrying mollusk was hampered by the presence of similar-looking, harmless shells, and because the habitat preference of the guilty mollusk was not completely understood. Military medical men, armed with malacological information, were able to track down the snail in every case.

Recognizing the guilty species of snail is not done by only studying the shell, but principally by observing the snail animal which is housed within. *Oncomelania* snails were found to possess a combination of animal characters not present in any other Philippine or Oriental snail—two delicate gray tentacles at the bases of which is a small black eye surmounted by a bright lunar splotch of yellow color granules. This last distinctive feature was referred to for convenient identification purposes as “yellow eyebrows.”

Studies on habitat preference had been hampered from the beginning. The Japanese who had been working on the problem had reported many years ago on the partially successful eradication method of scattering hot, unslaked lime in snail-ridden creeks. This had been misinterpreted in fairly recent American literature as meaning that crushed limestone and the changing of creek water from a slightly acid to a slightly alkaline condition would eliminate the snail. It took many months of water testing to show that temperature of the water, with the causative amount of shade and resultant amount of

oxygen in the water, was the chief factor. It was also discovered that the ideal condition of the water for the shedding of cercariae was on the slightly alkaline side. Today, the fact is almost universally accepted that a creature which builds its shell of calcium carbonate will grow best in slightly alkaline waters. The *Oncomelania* snail is amphibious, and although a gill-breather, is as much at home on the moist earth bordering the creeks as it is under water. If the water is cool, the mollusk will make no attempt to leave. If trapped in a small puddle of water from a previous flood, and if the temperature rises above 88° F., it will either crawl out over moist ground or, if the water is still slowly draining to the main creek, will come to the top, cup its foot to the surface film and float to cooler safety.

This matter of temperature and habitat preference is not without its far-reaching military aspects when it comes to locating safe areas for encampment. Two similar-appearing valleys can, by the nature of their drainage and terrain, possess totally different mollusk populations. On Leyte Island nearly any flat stretch of fairly well-shaded and creek-drained land may be looked upon as good breeding grounds for the *Oncomelania* snail. The bordering hillside streams are, without exception, perfectly safe. However, on Samar Island, at the northeastern end, a small valley tucked away in the hills was found which presents a totally different type of snail distribution. It is an area much like one that our troops might have entered had an assault on Japan been necessary. The center of the valley had every outward appearance of being snail-ridden country, yet a thorough survey there would have given a clean bill of health. The bordering hills, lush in protective woodland and near a source of clean, running water, would have been automatically recommended as an ideal site for encampment. Yet, unlike Leyte conditions, the areas around these hillside streams were heavily colonized by *Oncomelania* snails. The valley proper was ideal as a habitat in every respect except one—the temperature of the water was above 88° F. Had the inhabitants of our hypothetical Japanese valley fled, so that no survey could have been made of the natives, 1 to 2 months might have elapsed before the presence of the disease had become known. By that time our infected troops might have been holding an important sector of a battle front.

Locating small endemic areas of schistosomiasis has been made difficult by the migration of thousands of people during and after World War II. This has been particularly the case in the Philippine Islands and China. Medical surveys brought to light cases of the disease in areas which had always been thought to be free. Questioning usually revealed the fact that the patient had lived in or passed through an endemic area. The Navy unit employed an accurate and easy method of mapping out small endemic areas by trapping and inspecting wild rats. In the Philippines the rats which forage in the brush do not

migrate for any appreciable distance, for their food supply from fallen and broken coconuts is always plentiful. The rat acts as a blind reservoir host, catching the disease in the creeks, but apparently not passing schistosome eggs in their feces. A glance at a smear preparation of the liver under the microscope will show whether the rat is infected or not. In temperate regions of China and Japan the rat method is usually unsuccessful for locating endemic areas, for the animals prefer to remain near houses and barns and are not as likely to become infected.

Control measures against the snail were undertaken jointly by the Army and Navy. As a preliminary to chemical tests, the life history of the snail had to be known, for eliminating all visible snails might prove useless if, unknown to the workers, a habit of migration or secluded aestivation existed, or if the eggs of the snail could resist poisons. Two types of experiments were carried out to determine if the snail had a habit of migrating. The first was simply by setting a marker in a creek and liberating 500 snails whose shells had been painted bright yellow. Two weeks later 90 percent of the marked snails were recovered within 25 feet of the marker. Other observations involved the method of parasitological examination. At the edge of a marsh on the south side of the town of Palo a drainage ditch empties its schisto-polluted filth into the area of an extensive colony of *Oncomelania* snails. At the mouth of the ditch, where schistosome eggs were hatching into miracidia by the thousands, it was found upon microscopic examination that the snails were heavily infected with cercariae. Snail samples taken progressively farther from the ditch, and hence in zones of less miracidial exposure, showed lower and lower percentages of infection. Since the lapsed time from miracidial penetration to cercarial development is 8 to 9 weeks, it was safe to assume that the snails do not voluntarily migrate more than a few feet for at least that period of time.

The search for the egg of the *Oncomelania* mollusk lasted for 3 months. The size and nature of the egg were unknown to the Navy workers, and females kept in captivity could not be induced to lay. Mollusk eggs of a dozen species found in the creeks were carefully raised to an advanced stage of development so that identification could be made, but in every case they were found to belong to other species. The thrill of finally finding *Oncomelania* snail eggs was one which only comes to a naturalist engrossed in such strange searches. The egg was not only of extremely small size, no larger than the head of a pin, but was always carefully camouflaged by the feces of the female. The excrement of this snail is made up almost entirely of fine bits of undigested grit and sand. As the egg leaves the oviduct and is stuck to the surface of a moist piece of wood or coconut shell, the female places a number of her sandy fecal pellets on the egg and

pats them down into a protective, camouflaged jacket. With eggs available, the long list of chemicals effective against the adult was tested until all were eliminated save two which killed not only *Oncomelania* adults and their eggs but spelled death to the fork-tailed cercariae.

OTHER PARASITIC DISEASES CARRIED BY MOLLUSKS

In other parts of the world there are two additional blood-fluke diseases which have plagued the human race since the memory of man. One of these, bilharzia, is mentioned in early Egyptian records, and its presence has been discovered in Egyptian mummies dating from 1250 B. C. Napoleon's troops were infected in the Nile region, and during World War I the disease became familiarly known among British Tommies as "Bill Harris' disease." It has been estimated that 39 million people in Africa are at present suffering from bilharzia, with 6 million cases alone in Egypt. This almost equals the 46 million estimate for Oriental schistosomiasis. Bilharzia blood flukes take their toll of human lives by attacking the urinary system. The life cycle of the worm must include an intermediate snail host, as is the case with all trematode worms. It is rather odd, however, that this species of schistosome, so closely related to the Oriental type, is obligated to live part of its life in a lung-bearing snail which is not even remotely related to the gill-bearing *Oncomelania* snail.

The third type of schistosomiasis, Manson's disease, is of more interest to Americans, for its prevalence in Puerto Rico, the Lesser Antilles, and the northern parts of South America presents a serious menace to tourists who enjoy fresh-water swimming. Manson's disease is believed to have originated in Africa where today it is second only to bilharzia as a trematode menace. It has been thought that its presence in the Western Hemisphere is attributed to early slave trade. The snail responsible for the spread of this disease is related to the bilharzia carrier in Africa.

In addition to the three blood-fluke diseases, there are some half dozen other snail-borne diseases which directly affect the health and economy of millions of our fellow beings. These differ from schistosomiasis in being less damaging to the body, but are perhaps biologically more interesting in having developed strange variations in their life cycles.

The lung fluke, according to recent surveys, is at present limited to about 3 million cases of infection in Asia and a few thousand in West Africa. The half-inch-long adult attaches itself to the inner walls of the lungs and often produces fatal tuberculosis-like lesions. No effective cure is known. The eggs of the fluke are coughed out of the lungs into the river where they hatch into snail-seeking miracidia. This spe-

cies nearly always seeks out the river snails of the Thiariid family. In contrast to the simple schistosome life cycle, the lung fluke spends only a part of its larval life in the snail, and then emerges again to seek out a second intermediate host, this time a fresh-water crab or crayfish. The crustacean must be eaten raw by man in order that the lung-fluke larvae may penetrate the intestinal walls and migrate to the lungs. One marvels that such a disease can continue to flourish with so many weak links in its long and complicated life chain. In the Shoahsing area of Chekiang Province, China, famous for its good wines, a large proportion of the population is infected with lung flukes because of the native custom of eating uncooked crayfish that have been dipped in wine.

Peculiar and unchangeable eating habits of man are again responsible for the world's largest endemic area for the bile-fluke disease which affects several million people in the Canton areas of southern China. The life cycle of this fluke worm includes a mammalian host, usually man, dogs, or cats, a first intermediate snail host, and a second intermediate fish host. The infectious larval stages of the worm are embedded in the flesh of the fish, and must, as in the case of the crayfish, be eaten uncooked. Raw fish is consumed as a delicacy by the Cantonese during the fall festival season. Strips of the more succulent parts of the fish are dipped in hot tea or hot rice gruel, and are thus only partially cooked. Many of the natives cannot afford sufficient fuel to cook the fish thoroughly, and thus become infected.

THE SNAIL PROBLEM IN THE UNITED STATES

No sooner had the schistosomiasis epidemic among our troops in the Philippine Islands been quelled, when Public Health authorities, under the leadership of Dr. Willard Wright, turned their attention toward the possibility of an outbreak in our own country. Although schistosomiasis has never been contracted in the United States, the recent return of infected service personnel presents a potential threat. To determine whether or not domestic species of snails are capable of serving as intermediate hosts, Dr. Eloise Cram, parasitologist, and Dr. Elmer Berry, malacologist, have been carrying out an intensive study of this matter. Living specimens of many of our American species are shipped from the field to the aquarium rooms of the National Institute of Health in Bethesda, Md. There they are exposed to the various trematode diseases under study.

Already, one species of Tropicorbid snail sent in from Louisiana has been shown to be capable of acting as an intermediate host of Manson's disease. The native habitat for this species is the island of Cuba, with a few scattered records in Louisiana and Texas. These latter records may represent accidental introductions by man. Laboratory infec-

tions do not necessarily forecast what may happen in nature. Schistosomiasis is unknown in Cuba where the snail is rather common, and where undoubtedly infected visitors have given the disease every opportunity of becoming established. A number of parasitologists believe that the slave trade, with its accompanying cases of the two kinds of African schistosomiasis, has served as a great natural "experiment" in which it was clearly demonstrated that neither of the diseases were able to establish themselves in this country. It is probable that slaves were able to introduce Manson's disease into Puerto Rico, the Lesser Antilles, and northern South America because of the presence of a suitable snail host. A similar "experiment" occurred in the Canal Zone during World War I where a few infected Puerto Rican troops were stationed. The disease did not establish itself in that area, nor have mollusk surveys brought to light species of known carriers.

Research on the potential American snail carriers of Oriental schistosomiasis has been intensified recently by the promising early experiment of Dr. Horace Stunkard at Princeton. He has found that the *Pomatiopsis* snail can be infected by the Oriental disease, but has been unable, so far, to have the larval worm complete its growth. Present experiments now being continued at the National Institute of Health may meet with further success. The *Pomatiopsis* snail, already well known as a carrier of animal lung flukes in this country, is extremely close in its morphology and amphibious habits to the Oriental schistosomiasis carrier. In fact, it has been dubbed the "*Oncomelania* snail of North America." Its distribution, as shown by the accompanying map, is limited to the central regions of the United States except for a minor area of dispersal along the central portion of the Atlantic coastal plain.

By far the weakest link in our public-health defense is in future accidental introductions of known snail carriers from foreign countries. A number of slugs and other garden pests, including the giant African land snail, have already found their way to our shores. No disease carriers have been found in the United States as yet. The possibility of this is not too remote, as is demonstrated by the recent introduction and establishment of a Brazilian race of the Australorbid snail carrier of Manson's disease on Luzon Island, Philippines. It may be only a matter of time before the disease finds its way from Africa or the West Indies to the Philippines through the agency of some infected traveler. The importation of living snails into this country is subject to the fine-toothed combings of our plant quarantine and control agents, but this is not necessarily a perfect screen. Once here, the *Oncomelania* snail has ample room for spreading, and would probably follow much the same distribution of the *Pomatiopsis* snail. As long as the accidental introduction is discovered within a year or two, no harm will have been done. Newly introduced species usually

take two or three mating seasons to build up their population to the point where they begin to spread for more room. Fortunately, our leading natural history museums are in constant touch with thousands of mollusk amateurs and naturalists in the United States. From past experiences we know that any "new species" of mollusks discovered by

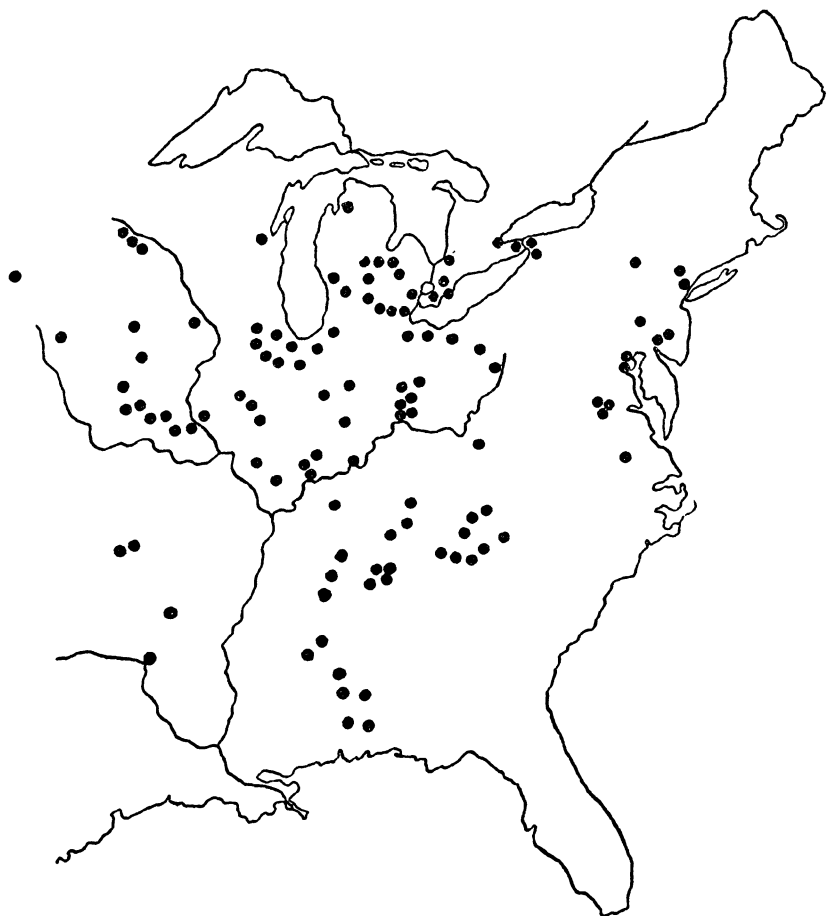


FIGURE 1.—The distribution of the *Pomatiopsis* snail, a relative of the Oriental carrier of the blood-fluke disease, is limited to the eastern third of the United States. Black dots show the locality records for *Pomatiopsis lapidaria*.

amateurs are promptly sent to professionals for naming. In this way any molluscan stranger is likely to come to the attention of malacologists aware of the danger.

SUMMARY OF MOLLUSCAN INTERMEDIATE HOSTS

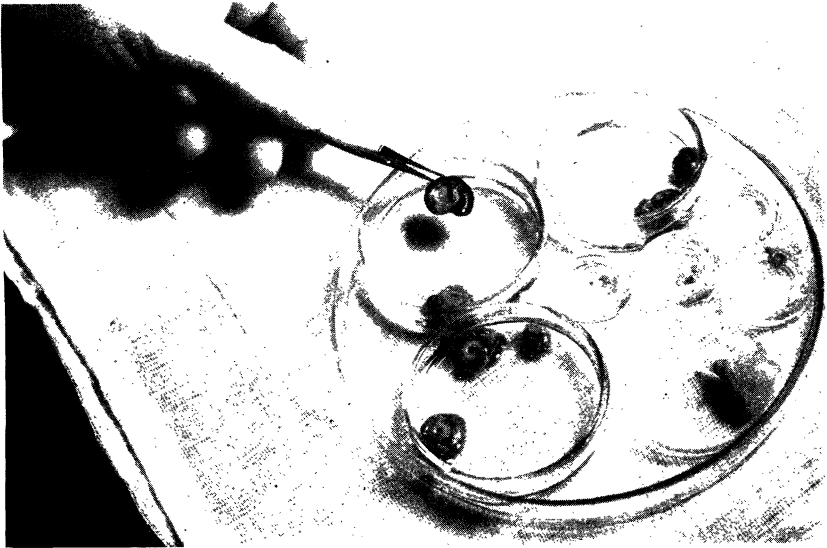
In order to avoid belaboring this article with scientific names, a table of human trematode diseases and their molluscan intermediate



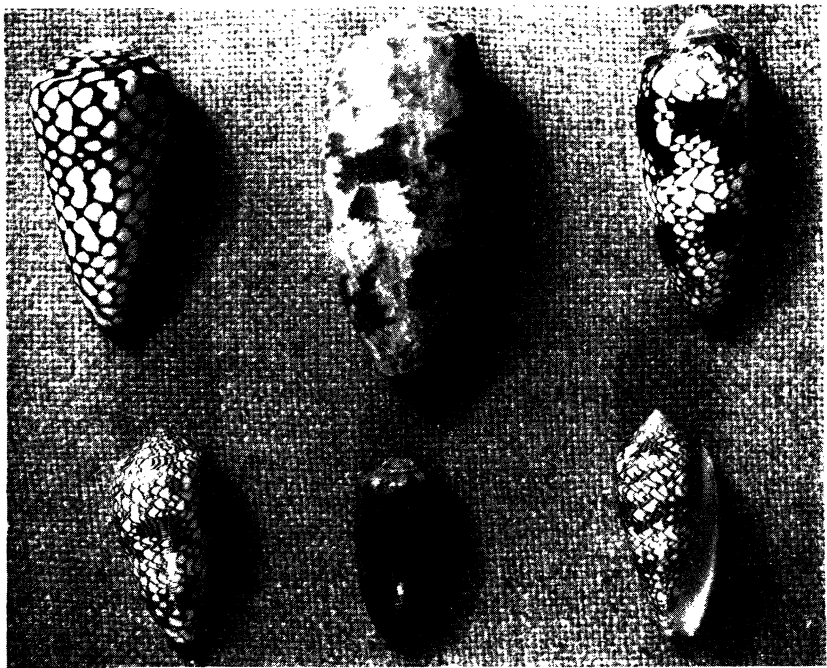
1. A handful of innocent-looking snails—yet they put a battalion out of action on Leyte Island, Philippines. (Navy photograph.)



2. An advanced case of snail fever or schistosomiasis. The liver of this Filipino boy will continue to enlarge until death occurs. (Navy photograph.)



1. Experimental snails infected with deadly schistosomes. The specimen being held is the West Indian carrier of Manson's disease. (Photograph by Perry, National Institute of Health.)



2. The venomous cone shells of the Indo-Pacific are collector's items, but are capable of inflicting a fatal sting. Top row, left to right, the marble, geography, and courtly cones; lower corners, the textile cone; lower center, the tulip cone.



1. Dr. Willard H. Wright (left), chief of the Division of Tropical Diseases at the National Institute of Health, and Dr. Eloise Cram carry on experimental work to safeguard our country from the introduction of snail-borne diseases. (Photograph by Perry.)



2. The laboratories in the Division of Tropical Diseases at the National Institute of Health are constantly receiving living snails from all parts of the country. Each species of snail undergoes rigorous tests to determine its disease-carrying potentialities. (Photograph by Perry.)

TABLE I.—*Human trematode diseases and their intermediate hosts*

Disease	Estimated number of cases ¹	Distribution	First intermediate small host	Second intermediate host
Oriental schistosomiasis (<i>Schistosoma japonicum</i>)	46 million	Philippines, China, Japan, Formosa.	<i>Oncomelania quadrasi</i> <i>Oncomelania hupensis</i> <i>Oncomelania nosophora</i> <i>Oncomelania formosana</i> <i>Bulinus truncatus</i>	None.
Bilharziasis (<i>Schistosoma haematobium</i>)	39 million	Africa		None.
Manson's disease (<i>Schistosoma mansoni</i>)	29 million	West Indies, South America, Africa.	<i>Afroplanorbis boissyi</i> <i>Australorbis glabratus</i> <i>Parafossarulus manclowricus</i>	None.
Bile-fluke disease (<i>Clonorchis sinensis</i>)	19 million	Eastern Asia	<i>Alotima longicornis</i> <i>Hippeutis schmackeri</i>	Fresh-water fish.
Intestinal-fluke disease (<i>Fasciolopsis buski</i>)	10 million	Eastern Asia		Encysts on water chestnut.
Lung-fluke disease (<i>Paragonimus westermani</i>)	3 million	World-wide Tropics, especially Far East.	<i>Semisulcospira libertina</i> <i>Thiara granifera</i>	Fresh-water crustacea.
Swimmer's itch (Schistosome species)	Hundreds each summer.	North-central United States.	<i>Lymnaea</i> species	None.
Animal lung fluke (<i>Paragonimus kellicotti</i>)	Unknown	Central United States	<i>Pomatiopsis lapidaria</i>	Crayfish.

¹ Taken from Norman S. Stoll, Journ. Parasit., vol. 33, No. 1, pp. 1-18, 1947.

hosts is given herewith. Only the more important diseases are listed and for each of them only the most important snail carriers. Insignificant trematodes of man, such as *Heterophyes heterophyes*, *Haplorchis pumilio*, and *Echinochasmus perfoliatus*, have been excluded. Doubtfully or accidentally implicated mollusks such as *Syncera lutas*, *Thiara (Melanoides) tuberculata*, and others have also been left from the list. The trematode, *Paragonimus kellicotti*, at the bottom of the table is not a human-infecting species, but its intermediate snail host, *Pomatiopsis lapidaria*, is considered a potential host of Oriental schistosomiasis.

THE VENOMOUS CONE SHELL

Seashell collecting and the handicraft of shell jewelry became popular hobbies among many of our troops stationed on remote Pacific islands. The coral reefs of the South Seas and the East Indies underwent the most intensive scouring for rare and beautiful specimens since the days of early natural history exploration. Yet despite the many hazards of reef collecting, relatively few accidents and no cases of fatal bites and stings were recorded. This may be accounted for, in part at least, by the wide circulation of information on poisonous foods and animals given in survival handbooks by the Army and Navy.

Among the most dangerous inhabitants of the coral reefs are the cone shells whose sting is equally as powerful as the bite of a rattlesnake. Although the beautiful cone shells are one of the commonest of Indo-Pacific mollusks, the total list of authentic cases of death by their sting is not at all impressive. Of the many dozen species found in this region, only five have been known to produce a venomous sting. The number of cone-shell stings is few because of the shy nature of the animal. Invariably a snail will withdraw into its shell when disturbed, and unless the cone shell is held quietly in the palm of the hand for some minutes, there is little likelihood of the collector being stung.

The apparatus for the injection of venom into the skin of the victim is contained in the head of the animal. Bite, rather than sting, is perhaps more descriptive of the operation. The long, fleshy proboscis or snout is extended from the head and jabbed against the skin. Within this tube are a number of hard, hollow stingers, slender and long as needles. These are actually modified teeth or radulae, commonly used in other snails to rasp at their food. Under a high-powered lens the teeth of the cone shell resemble miniature harpoons. As the teeth are thrust into the skin, a highly toxic venom flows from a large poison gland located farther back in the head, out through the mouth, and into the wound through the hollow tube of the tooth.

There have been a number of graphic accounts of the symptoms

involved in cone-shell stings, two of which are quoted below. Dr. H. Flecker, in *The Medical Journal of Australia*, vol. I, 1936, reports that—

C. H. G. [Charles H. Garbutt], a male, aged 27 years, whilst on a pleasure cruise landed at Haymen Island on June 27, 1935, and picked up a live cone shell (since identified by Mr. H. A. Longman, of the Queensland Museum, as *Conus geographus*). According to an eye-witness, it was gripped in the palm of one hand, with the open side downwards in contact with the skin, whilst with the other he proceeded to scrape with a knife, the epidermis, that is, a thin cuticle covering the hard part of the shell. It was during this operation that

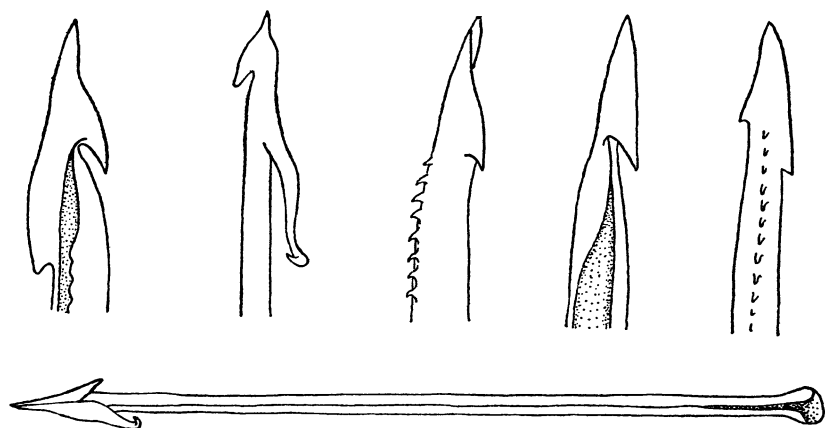


FIGURE 2.—The needlelike tooth with which the venomous cone shell stings its prey. The top row shows the harpoon-shaped heads of the teeth of five venomous species. Left to right, *Conus textile*, *striatus*, *geographus*, *marmoreus*, and *tulipa*. Magnified 50 times.

he was stung in the palm of the hand. Just a small puncture mark was visible. Dr. Clouston did not see the patient until just before death, but following details were obtained by him from the patient's mother, who was present with him. Local symptoms of slight numbness started almost at once. There was no pain at any time. Ten minutes afterwards there was a feeling of stiffness about the lips. At 20 minutes the sight became blurred, with diplopia; at 30 minutes the legs were paralysed; and at 60 minutes unconsciousness appeared and deepened into coma.

No effect was noted upon the skin, lymphatic, alimentary or genito-urinary systems. Just before death, the pulse became weak and rapid, with slow, shallow respiration. Death took place 5 hours after the patient was stung.

A post mortem examination showed that all the organs, heart, lungs, et cetera, were quite healthy. Mr. J. B. Henderson, Government analyst, reports that no poison was found in the stomach contents. The victim was prior to the injury in perfect physical condition and in training for football.

In the other species of cone shells, the reports show that considerable pain accompanies the sting. Andrew Garrett, a famous shell collector of the latter half of the nineteenth century, reported that he was stung by a *Conus tulipa* "causing sharp pain not unlike the sting of a wasp."

Another case was recorded in Japan by H. Yasiro (Venus, vol. 9, pp. 165-166, 1939). The translation of this paper appears anonymously in the proceedings of the Malacological Society of London, 1940, vol. 24, p. 32.

On 29 June 1935 a man 32 years old left home about 10 a. m. for bathing and shell-collecting. Soon after he was infected by the bite of a *Conus geographicus*. He immediately felt great pain and scarcely managed to walk home. A doctor attended promptly; the patient's temperature arose to about 36° C. (= 113° F.), breathing became difficult and his finger-tips went purple. He was soon unconscious and died about 3 to 4 hours after infection.

Other cases, not all fatal, have been recorded from New Guinea, New Hebrides, New Caledonia, Tonga, Samoa, Fiji, the Carolines, and the Society Islands. An excellent and much fuller account of the various cases appeared in a recent article by W. J. Clench, curator of the department of mollusks at Harvard College (Occasional Papers on Mollusks, Harvard University, vol. 1, No. 7, pp. 49-80).

The cone shells apparently use their venomous armature primarily for the purpose of subduing their prey. Fish, crab, and mollusk remains have been found in the crop and stomach. Secondly, the cone shells use their sting as a means of defense against such enemies as the octopus. Recently in Queensland, Australia, the effectiveness of the cone shell's defense was demonstrated during the course of a shell-collecting trip on the reef. An 18-inch octopus had been captured and put alive in an enamel pail of sea water. Later, a venomous cone shell was found and dropped in with the octopus. In a few minutes the latter began to attack the cone shell with its customary procedure by placing one of its tentacles across the mouth of the shell. Under normal circumstances it takes an octopus a few minutes to dig and suck a snail animal from its shell, but in this case it suddenly withdrew its hold, waving its tentacles about in violent agitation. Immediately after the retreat of the octopus, the tiny, needlelike radula of the cone shell could be seen slowly withdrawing into the snail's proboscis. A few minutes later the octopus shed one of its tentacles. Although the creature was soon transferred to a well-aerated tank of fresh sea water, it was found dead the following morning. The venomous cone shell, on the other hand, remained healthy and active for many more days.

The species of cone shells reported in the literature as having been responsible for deadly stings are the tulip cone (*Conus tulipa*), the textile cone (*Conus textile*), the geography cone (*Conus geographus*), the marble cone (*Conus marmoreus*), and the courtly cone (*Conus arlicus*). Oddly enough, the nature of the cone-shell poison has never been investigated by a chemist. The marlinspike shells of the genus *Terebra*, a cousin of the cone shells, are also armed with harpoonlike teeth and a small poison gland, but to date no records of their inflicting a sting in man have appeared in the literature.

SOME REMARKS ON THE INFLUENCE OF INSECTS ON HUMAN WELFARE¹

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The ways in which insects affect human welfare are so numerous and diverse that no approach to completeness of treatment can be made in a brief paper. In the present instance, however, completeness is not needed, nor in fact is even a comprehensive sampling. A consideration of certain aspects of the subject will suffice, for the object of the paper is to advance the thesis that the time has come for entomologists to present to the public, on whose support the progress of entomological research almost entirely depends, a more balanced interpretation of insect and human relations than that usually current.

The subject of insects and human welfare is not new, and certain aspects of it have been developed at length in a great variety of books, technical bulletins, magazine articles, newspaper stories, and even reports over the radio. The relationships that have been most frequently stressed, perhaps naturally enough, have been those in which insects appear as enemies of man. It is not my desire to minimize the damage inflicted on man by those insects which are agricultural or forest pests, transmitters of disease, or are in other ways inimical to man's well-being. Such damages, however, and the insects responsible for them, should be viewed in proper perspective. In no other way can the real importance of insects as a whole be understood correctly and evaluated properly.

It has long been apparent to biologists, whenever insect and human relations are viewed in their entirety, that the insect species which are injurious or antagonistic to human welfare actually constitute only a small proportion of the total of insect life and that the great majority

¹ Presidential address read before the Pacific Coast Entomological Society, January 4, 1947. Reprinted by permission from *The Pan-Pacific Entomologist*, vol. 23, No. 1, January 1947.

The aim of this paper is to focus attention on influences exerted by insects in ways that are independent of those due to conflict among the insects themselves. Consequently, the discussion omits entirely the well-known beneficent aspect of the work of parasitic and predatory insects in controlling species that are real or potential pests, in order that other and less familiar benefits that man owes to insects may be given due emphasis.

of insects are either directly or indirectly beneficial to man or enjoy a neutral status. Dr. Frank Lutz (8)² has estimated that not more than one-half of 1 percent of all the insects in the United States are actually pests. Calling attention to Lutz's estimate, Paul Knight (7) states that "those who care to extend the argument can show that a far greater percentage are of direct value, but that would prolong a question that is scarcely debatable." Nevertheless the beneficial aspects of insect activities have not been brought clearly to the attention of people generally.

It is still too common practice on the part of entomologists, and in particular of economic entomologists, since they must perforce focus their attention on destructive species, to ignore or to minimize the numerous benefits conferred on man by insects. For example, Graham, in "Principles of Forest Entomology," (6) recognizes the beneficial role of numerous forest insects, but dismisses them with a paragraph of brief consideration in the final chapter.³ An occasional text, such as "Destructive and Useful Insects," by Metcalf and Flint (9) devotes a full chapter to the benefits that man derives from insects, and a very few treat the subject at more length, but in the majority of texts the treatment is quite inadequate.

All too often, especially in articles designed for popular consumption, we encounter extravagant statements and overdrawn pictures concerning the so-called warfare between man and the insects as if the two were engaged in a relentless struggle to the death. The "insect menace" has become a catch phrase. To be sure, most of these fantastic pictures are found in articles written by persons lacking entomological training. Not a few, however, have been prepared by entomologists who should know better and nearly all are based on information and ideas that have been supplied by entomologists. An unfortunate consequence of this state of affairs is that many, if not most, laymen have developed the belief that nearly all insects are injurious and should ruthlessly be exterminated.

A few decades ago excessive emphasis on the destructive activities of insects perhaps was justified. The increasing number of insect pests required that public attention be directed to these enemies of agriculture. Without this emphasis it might not have been possible to arouse the public sentiment and the legislative backing that were essential for the support of needed research on pest control. At that

² Numbers in parentheses refer to bibliography.

³ The omission referred to here is the omission of any general treatment of beneficial insect activities in the forest such as are dealt with here. There is no intent to imply that Dr. Graham is unacquainted with these activities or unappreciative of them. Dr. Graham is a good ecologist and his book contains numerous scattered references to the beneficial activities of forest insects. The intent is merely to note that it has not been the custom in general texts such as Graham's, concerned as they are with the control of insect pests, to present beneficial insect activities broadly and as a whole, and so the student or general reader is likely to underestimate their importance.

time also a factual basis for an adequate appreciation of the beneficial aspects of insect life had not yet been sufficiently developed. For that matter, there is real need at the present time for extensive and detailed exploration of the beneficial activities of insects. In particular there is a need for quantitative studies. The knowledge we now possess is mostly of a qualitative nature.

The goal of an aroused public interest in the study of injurious insects has long since largely been achieved and adequate support for research in economic entomology usually is available. We now urgently need to round out the picture, to educate the lay public to a realization of the vast amount of good that is done by insects as a whole, to the end that balanced judgment shall determine the general attitude toward insect-human relations and that all branches of entomological research shall be recognized as meriting adequate support.

There is at present a measure of real danger that the lay public, animated by the conviction that insects constitute an enemy group, may attempt to carry the matter of insect control, or rather, suppression, too far. For the first time in the history of man's conflict with insects the materials at his disposal make the unwise dream of insect extermination seem possible of attainment, at least in localized areas; or if this state of affairs has not yet been attained, at least it seems to be not far away. If, therefore, man is to be spared costly experiences in which his actions bring down upon him more harm than good, it is essential that there be developed in the public mind an appreciation of the beneficial activities of insects that will serve to balance the already well-developed appreciation of their injurious activities.

The economic entomologist has a special responsibility in this connection because of his frequent contacts with a segment of the public which has a special reason for distrust of insects. Moreover, to ensure the proper development of economic entomology in the years that lie ahead, it is essential that the economic entomologist recognize and accept this responsibility as many of them individually already have done. It is becoming increasingly evident that the carrying out of proper measures for the control of injurious insects is not simply a matter of applying a sufficiently lethal insecticide. Rather it requires that each species be regarded in the light of the entire complex ecological picture of which it is a part, and that control measures be selected accordingly. It often happens that insects that are injurious under one set of conditions or circumstances are of no consequence or are beneficial under others. A correct appraisal of the economic status of many an insect, therefore, cannot be made by the farmer but only by a well-trained economic entomologist who has a broad knowledge of general insect ecology. A great deal of time and money is now wasted in so-called "insurance spraying" which might be saved or

better used in some other type of control. The farmer should be educated to expect the economic entomologist to have the broad type of training suggested above and to look confidently to the economic entomologist for immediate advice and guidance in meeting his problems of pest control. This desirable relationship cannot materialize so long as the current point of view continues to prevail.

It may be that the danger that I have envisioned is more apparent than real. Human affairs move with sufficient slowness that the unwisdom of attempts at the wholesale extermination of insects may be made sufficiently clear through repercussions from early attempts that efforts in this direction will be abandoned and will be replaced by actions based on a saner philosophy. Certainly the usage of DDT to date has revealed that such powerful insecticides, valuable as they are, cannot be used indiscriminately with impunity. Nevertheless much is to be gained by a concerted program of public education that is aimed at balanced enlightenment in place of the present program of merely seeking support for more and ever more destruction of insect life.

In the light of the reasoning thus far advanced it seems worth while to review certain of the interrelations between man and insects in which the insects play a beneficial role.

As a general rule little attention is paid to the factors concerned in the control of the plant population of the earth and the place that insects hold among these factors. Because of man's dependence on plants it is customary to label as injurious any creature aside from man and his domestic animals that feeds on plant life. Yet obviously this is not the case. An organism is really injurious only when it becomes sufficiently abundant that its activities are genuinely detrimental to the welfare of other organisms. This happens in the case of only a very small proportion of insects. Moreover, it is possible for a plant as well as an insect or other animal to get out of balance with the rest of life; to become, in fact, a pest. A few plants in recent decades have so far escaped from normal population controls as to become veritable scourges, and so far the only significant progress in bringing them back under control has been accomplished through the use of insects that feed on them.

The most notable example is the prickly-pear cactus in Australia which, according to some authorities, by 1935 occupied some 60,000,000 acres of Australian soil to the extent that it was practically worthless for agriculture. Cactus-feeding insects introduced from the Americas have brought the cactus under control. Most of the work of control has been wrought by a single species, the moth *Cactoblastis cactorum*, whose caterpillar mines the joints of the cactus. Allan P. Dodd (4) says the introduction of this insect between 1925 and 1927 "brought a complete change in the outlook within a few years. Its progress has been spectacular, its achievements border on the miraculous. Great

tracts of country, utterly useless on account of the dense growth of the weed, have been brought into production. The prickly pear territory has been transformed from a wilderness to a scene of prosperous endeavor."

Probably not many plants possess the qualifications for becoming pests of the magnitude of the cactus, but we have no way of judging beforehand. There are other weed plants besides cactus which, though perhaps less objectionable, have nevertheless become major pests in countries into which they have been introduced. Such are lantana in Hawaii and Australia, blackberry and gorse in New Zealand, and St. John's Wort in California. Success has been only partially attained to date in controlling these weeds but the measure of success that has been attained has been accomplished largely through the use of insects.

In the countries to which they are native these plants are not pests. They fit normally into the flora of those regions in mutual adjustment with other organisms. The factors that determine their normal population levels, as is true of plants everywhere, undoubtedly are several, but among these are the insects that feed upon them. Dr. Brues has pointed out in "Insect Dietary" that insects are a major factor in determining population levels in plant life. We perhaps cannot even guess accurately what the consequences would be if insects were to be totally removed from the realm of plant life, but we can be sure that it would be some sort of chaos and that man would be numbered among the victims of such a disastrous happening.

We are accustomed to looking upon insects that attack trees as injurious and requiring control, and certainly often, though not always, this view is the correct one. Yet it is equally certain that the majority of insects to be found in a forest are not detrimental to the forest and that many, if not the majority, actually benefit the forest in one way or another. F. C. Craighead (2) in "An Annotated List of the Important North American Forest Insects" lists less than 200 kinds of really destructive species distributed over many families, yet W. J. Chamberlin (1) records 575 species of bark and timber beetles in but two families. The great majority of these are forest species but the great majority are not destructive.

Chamberlin (loc. cit.) says, "When *Micrasis*, *Carphoborus*, *Pityophthorus*, *Pityokteines*, *Lymantria*, *Hypothenemus*, or any of the other similar species attack the lower limbs of trees and kill them, they are but hastening natural pruning which results in a clean bole and a better grade of lumber."

Doane, Van Dyke, Chamberlin, and Burke (3) say that "In every heavily stocked young forest there are thousands of trees that must die and pass out of the picture before the forest reaches maturity. * * * Nature takes care of this * * * need through

suppression of slower-growing trees; and at times insects and disease may serve a useful purpose in removing trees from overcrowded stands, thereby releasing the space to the surviving trees which will then grow more rapidly and into better wood material."

It is obvious, therefore, that without the beneficial services of numerous forest insects our forests would never have attained to their present magnificence, their productivity would be far less than it now is, lumber would be inferior, they would be less suitable as homes for valuable wildlife, and their esthetic and recreational values would be far less than they now are. They would, moreover, be filled with a tangled maze of dead branches and small trees that would constitute a fire hazard far greater than any now known, or what is more probable, they would be swept by destructive fires of such extent and with such frequency as never to attain the status of forest maturity as we now know it.

To consider another phase of the general problem, many insects inhabit the soil, often in tremendous numbers. In one case in Illinois their numbers were estimated at no less than 65 millions per acre. Some of the soil insects, namely wireworms, white grubs, certain aphids and mealybugs, and a miscellany of others, feed on the underground parts of plants, damaging them more or less, and at times attain the status of pests. The majority, on the other hand, make a definite, important, and perhaps essential, contribution to the development of the soil itself and to the maintenance of soil fertility.

Paul Knight (7) in this connection says—

(1) Soil organisms cause a continual interchange of soil particles by bringing to the surface particles of subsoil. The gradual enrichment of these soil particles increases the thickness of the rich top layer. (2) The burrows of soil organisms allow better drainage and aeration. (3) The dead bodies of animals such as insects and worms add a large amount of organic material to the earth. (4) The excreta of insects compares favorably in fertilizing value with the digestive wastes of other animals. Though the digestive waste of one insect is infinitesimal, the aggregate mass of all insect excreta probably exceeds that of the larger animals and is an important factor in soil fertility.

W. M. Wheeler (10), referring specifically to the soil-building activities of ants says, "Thus the ants act on the soil like the earthworms, and this action is by no means inconsiderable, although as yet no one has studied it in detail."

In the discussion of both of the preceding two topics—forest insects and soil-inhabiting insects—mention has been made of the effectiveness of insects as scavengers. Their value in this connection can more easily be underestimated than overestimated for they are second in importance only to the bacteria and fungi as agents of decay.

We deplore decay whenever it affects any type of material or product that we wish to preserve for a time. We deplore the existence of *Penicillium* fungi that destroy a part of the oranges or lemons that

we buy in the markets, we strive to prevent the growth of the several rot-disease fungi that destroy the foundation timbers of our homes and other buildings; we abhor the maggots that swarm through the carcass of a dead animal or a mass of garbage that has not been properly disposed of; but at the same time we recognize the general usefulness of decay. We know that decay is the necessary counterpart to life and without decay life would soon become impossible on the earth.

Folsom and Wardle (5) say that insects "as scavengers are of inestimable benefit, consuming as they do in incalculable quantity all kinds of dead and decaying animal and vegetable matter. This function of insects is most noticeable in the tropics, where the ants, in particular, eradicate tons of decomposing matter that man lazily neglects."

The importance of decay and the necessity for it lies in the fact that certain chemical elements, in particular nitrogen, phosphorus, and potassium, obtained from the soil by plants and needed alike by plants and animals, are present in usable form only in relatively small amounts in most soils. The available supply must be returned to the soil on the death of the organisms living on or in the soil if life is to be continued in anything like its normal luxuriance. Without the beneficial agency of the bacteria, fungi, insects, and other organisms of decay but especially these three, developing plant life would gradually but surely tie up in plant tissues almost all of the existing supply of critically needed mineral elements.

For the purpose at hand it is unnecessary to develop in detail additional aspects of the general topic. Simple mention or very brief treatment of some of these will suffice. All, in one way or another, are fairly well known to entomologists though not to the general public, or at least not sufficiently known.

The importance of insects as animal foods is apparent when we realize that considerably more than half of the food supply of common land birds, fresh-water fishes, many reptiles, and many small mammals consists of insects, and without the insects these animals would be unable to maintain themselves. It is customary to consider such animals as constituting checks on the increase of insects, and no doubt at times and perhaps continuously to a limited extent they do constitute such checks, but there is much evidence to indicate that more often the vertebrates in question, and in particular the birds, are merely living off of the surplus of insect life and are not a significant factor in regulating insect abundance.

The dependence of flowering plants on insects as pollen carriers has received wide attention. It is estimated that about 85 percent of flowering plants require insect pollination in whole or in part. Metcalf and Flint (9) estimate that the annual yield of agricultural crop

plants in the United States that depend on pollen transfer by insects has a value in excess of 2 billion dollars. In this field as in others, however, the picture that has commonly been drawn is an unbalanced one. Most discussions of the subject have been in terms of the honeybee and bumblebees. Admitting the tremendous importance of these insects, it must yet be recognized that there are thousands of species of plants for which the honeybee and bumblebee have no meaning. Great numbers of other insect species, solitary bees, flies, beetles, moths, and butterflies, and even, occasionally, such small creatures as thrips, function as pollinators of these plants and in numerous instances play an absolutely essential role. Without them a considerable proportion of our garden flowers and shrubs could not exist, nor could there be the wealth of color and variety in the wild plants that clothe our valleys and hillsides in proper season. Insects, therefore, make a contribution to the esthetic and recreational resources of man that is not inconsiderable.

Much of the vegetation that adds beauty to the desert areas of the earth consists of insect-pollinated plants. Such also is the case with the chaparral and other growths that hold back the runoff on hillsides and gentler slopes over vast acreages and so protect the lowlands from destructive floods.

In summation, it is perhaps impossible to visualize adequately the totality of beneficial effects which insects exert directly or indirectly on human welfare, but the benefits are incalculably great. It is not too much to say that insects determine the character of man's world to a far greater extent than he does himself, and that if they were suddenly to disappear completely the world would be changed so extensively that it is extremely doubtful that man would be able to maintain any sort of organized society whatever.

I repeat, therefore, that the time has come for entomologists generally, and for economic entomologists in particular, to present to a public that is manifesting increasing interest in insect life, a more rounded and better balanced picture of insect life. It is time to appeal for interest and support on the basis of this more complete picture and man's place in it, recognizing that all forms of life are interwoven in an integrated whole which needs to be understood before it can safely be changed in any radical manner, and that in arriving at this more intelligent basis for orienting ourselves to the insects there is no place for categorical condemnation or praise. On the contrary, each species or closely knit group deserves to be considered independently and judged on its individual merits.

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MOSQUITO CONTROL TESTS FROM THE ARCTIC TO THE TROPICS

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[With 8 plates]

Mosquitoes long ago put into practice a political theory publicized within recent years by the late Wendell Willkie. "One World," to these annoying pests and carriers of disease, has been and continues to be a reality. Not all of them, by any means, live here with us in the North Temperate Zone. In swarms they attack man and beast north of the Arctic Circle, and in myriads they inflict suffering and illness on inhabitants of the Tropics. The tropical diseases they carry include malaria, dengue, yellow fever, filariasis, and encephalitis.

Soon after we entered World War II our Army and Navy found mosquitoes a formidable enemy. The battle front on which they encountered these creatures was a long one; in the far North mosquitoes prevented rest and hindered outdoor activities, and on the Equator indirectly caused the loss of many thousands of man-days by transmitting disease. Few American entomologists had conducted mosquito surveys in either of these far-away zones, and few of us knew anything about their habits in foreign lands. Our military forces sorely needed an effective means of repelling mosquitoes. They needed also a modern, effective method of destroying mosquito adults and larvae over large areas under a wide variety of conditions. Several hundred species of mosquitoes were involved, varying widely in their bionomics.

In 1942, at the request of the office of the Surgeon General, United States Army, and with funds provided to the Bureau of Entomology and Plant Quarantine by the Office of Scientific Research of the National Emergency Council, entomologists at our laboratory in Orlando, Fla., began a long series of tests to develop effective mosquito repellents. Hundreds of new and old chemicals were sent to Orlando by chemical companies, from all parts of the United States. Within a few months several materials, having shown promise in the laboratory, were recommended for field tests.

TESTING MOSQUITO REPELLENTS IN THE ARCTIC

Late in June 1943 Terris Moore, of the Office of the Quartermaster General, United States Army, and I were detailed for a few weeks to

testing equipment including mosquito repellents in the vicinity of Churchill, Manitoba, Canada (8).¹ This Army outpost on the western shore of Hudson Bay was chosen for the tests partly because of its accessibility, but largely because it lies in the midst of some first-rate mosquito-breeding country. In my naive, provincial way I thought I had already seen mosquitoes on the loose, but I was not prepared for the countless numbers of *Aedes* that accompanied us almost constantly on our daily routine at Churchill. They rode on our protected backs for miles through the muskeg, they cluttered the window screens of our barracks in a vain attempt to get food, and they entered our cargo planes and traveled for miles in every direction. On one trip to Southampton Island, in northern Hudson Bay, thousands of the insects took off from Churchill with us and made it easily to the next stop 500 miles distant. En route, the temperature soon became too low for much activity on their part; but upon landing at Coral Beach they swarmed up and soon tried to bite.

Moore and I arranged a simulated forced march of several days through the muskeg (9). Two Medical Corps officers, Capt. S. M. Fierst and Lt. D. A. Tutrone, and 12 enlisted men were detailed to accompany us. Without benefit of trails, shelter, or food other than what we carried on our backs, we headed into the wilderness. Everywhere the ground was wet from the melting of ice a few inches below the surface. Travel was tough, and our feet were constantly wet. Every afternoon we spent hours seeking an elevation high enough on which to make our camp. We wore heavy clothing, partly as a protection against mosquitoes and partly as insurance against being chilled by sudden snow or northern wind storms. Fighting mosquito hordes while wearing heavy clothing and loaded packs during days when the temperature occasionally rose above 80° F. was not so difficult as preparing for meals and sleeping. While we were eating we could not wear gloves and headnets and continually dope ourselves with insect repellents, consequently the insects were constantly attempting to bite our hands and faces. At nearly every meal, numbers of mosquitoes accidentally landed in everyone's beans and coffee.

The object of our hike was to determine which gave better protection—heavy clothing, or the chemical mosquito repellents we had brought from the Orlando laboratory. One day we would try double layers of heavy clothing, without repellents. The next, our Army personnel would serve as human guinea pigs. Their faces would be protected with head nets, but their arms and legs would be left bare and we would apply a different repellent to each of a man's bare arms and legs. We would then clock the time between application of the repellent and the first, second, and third mosquito bites (table 1). The

¹ Numbers in parentheses refer to bibliography.

different repellents gave protection for different lengths of time on different hosts, but in general the effective period was shortest for Indalone and longest for the three-way mixture 6 parts dimethyl phthalate, 2 parts Indalone, and 2 parts R-612. The repellents were applied carefully and thoroughly, and after each application we washed our hands with acetone to avoid contaminating any one repellent with any other. We would test but one repellent on any one arm or leg during the course of any one day. On any day when the biting rate of mosquitoes was abnormally low because of unfavorable weather, we interrupted the test repellents and instead tested some tents and sleeping bags Moore had designed. From time to time we used jungle boots and jungle hammocks. The hammocks were warm and comfortable, and after we got inside we were well protected against mosquito bites—that is, unless an arm or leg came into contact with the netting. Wearing jungle boots in that cold and saturated moss-covered muskeg was another story, and none of us volunteered to test them a second time.

TABLE 1.—*Repellent test. Mosquitoes: Aedes nearcticus, Aedes cataphylla. July 7, 1943, Churchill, Manitoba. Biting rate, 61 per minute*

Host, ¹ and number of bite	Duration, in minutes, ² of protection given by indicated repellent			
	Indalone	Dimethyl phthalate	R-612	"6-2-2" ³
Kettler:				
First.....	43	92	108	91
Second.....	65	108	147	100
Third.....	68	128	151	130
Average.....	59	109	135	107
Walker:				
First.....	69	102	112	70
Second.....	82	111	119	160+
Third.....	83	116	142	160+
Average.....	78	108	126	130+
Abrams:				
First.....	98	62	112	160+
Second.....	103	66	120	160+
Third.....	104	72	137	160+
Average.....	101	65	120	160+
Walaszewski:				
First.....	111	68	142	160+
Second.....	152	160+	160+	160+
Third.....	160+	160+	160+	160+
Average.....	141	129+	144+	160+
Grasso:				
First.....	77	113	160+	160+
Second.....	96	160+	160+	160+
Third.....	98	160+	160+	160+
Average.....	90	144+	160+	160+

¹ Each host tested 4 repellents simultaneously, 1 on each arm and each leg.

² Plus sign signifies that test was terminated at the end of the time indicated because of rain.

³ A mixture containing 6 parts dimethyl phthalate, 2 parts Indalone, 2 parts R-612.

Trying to dry our feet and socks before going to bed was about the most uncomfortable experience of all. We had the minimum of change and had little heat to dry our clothing, and mosquitoes were constantly finding vulnerable parts of our anatomy. We took turns using a specially designed sleeping bag, without benefit of a tent. Getting partly undressed and diving into a sleeping bag fast enough to escape being bitten was a real feat. There remained, then, the attempt to zip up the sleeping bag and stuff mosquito netting into the opening through which we breathed. Our arms were pinned to our sides, there were persistent lumps in our improvised mattresses of reindeer moss, and daylight lasted until 10 or 11 p. m. The sun arose about 2 in the morning, and if the night was not exceptionally cold our rest was punctuated by the monotonous hum of the mosquito hordes.

One evening when most of the boys had retired to their small pup tents I made a fairly dependable count of 1,900 mosquitoes quietly roosting on one of the tents. These tents had a canvas floor, a screened ventilator in each end, and two doors—one of mosquito netting, the other of canvas. Two men were assigned to each tent. As the men crawled into their tents, many mosquitoes went right in with them. I had brought a supply of aerosol bombs, and after each pair of men crawled into their bedding I released the pyrethrum aerosol for a few seconds in through their netting door. This treatment entirely freed the inside of the tent of living mosquitoes within a few minutes. In the ventilators of one such tent I counted one morning 128 dead mosquitoes. No doubt dozens of others had been killed by the aerosol before they were able to get to the ventilator. Had it not been for the aerosol bombs, each of our nights spent in the tents would have been one of torment.

The results obtained with our insect repellents (10) compensated Moore and myself for the tortures the mosquitoes inflicted upon us, but the enlisted men did not share our enthusiasm. All but one of them, however, stayed with us until the tests were completed.

We obtained data on the relative merits of several repellents used alone and in different combinations (20). As in the laboratory at Orlando, certain repellents proved effective on some individuals but not on others, and a mixture of the three most effective repellent chemicals proved more effective on all individuals than any repellent used alone. We demonstrated that these new materials could be used for the protection of our armed forces under Arctic conditions. At the end of our tests a secret ballot was taken in which each man was asked to indicate whether he preferred to be protected with heavy clothing or with repellents. The vote was unanimously in favor of the repellents.

In all our tests, the number of mosquitoes alighting on a certain portion of the unprotected leg or arm was at least 45 per minute.

Invariably, the culprits belonged to the genus *Aedes*. They represented three species, *A. cataphylla* Dyar, *A. nearcticus* Dyar, and *A. excrucians* (Walk.). We found no convincing evidence that one of these species was more difficult to repel than the others.

Preliminary information was obtained on the attractiveness or repellency of color to mosquitoes. On a bright, moderately warm day when the temperature was in the high 70's, we asked the soldiers to wear black, white, and tan (OD #3) shirts. While they stood in a row we counted the mosquitoes landing on certain areas on the backs of the shirts every 30 seconds for 20 minutes. The shirts were also rotated on the several men. Two volunteers bared their backs for short periods from time to time. Each 30 seconds, on an average, 4 mosquitoes landed on a white shirt, 15 on a black shirt, 31 on a tan (OD #3) shirt, and 97 on a bare back. Thus it appeared that color is of considerable importance in influencing the number of mosquitoes naturally alighting on a man's shirt-clothed back, nearly 8 times as many alighting on the tan shirt as on a pure white one.

TO ALASKA IN 1944

So far as was compatible with the exigencies of war, the office of the Surgeon General, United States Army, wanted to get information on the species of mosquitoes in the Territory of Alaska, their relative abundance, and the locations where they were and were not important. On July 5, 1944, I flew from Seattle to Alaska, and during the remainder of that summer I covered about 8,500 miles by air and 600 miles by automobile in an effort to obtain such information. Again, the data obtained were decidedly preliminary; even so, we made the first record of the fact that mosquitoes are not a pest on Kodiak Island or on the islands of the Aleutian chain. I encountered swarms of several species of mosquitoes in the vicinity of Nome, although the National Museum had but one previous record of mosquitoes from that northern village (16). Flying north of the Arctic Circle, I found hordes of a group of species different from that common 300 or 400 miles south (11). Inland for 200 miles over the American Range northeast of Nome the species were predominantly different than those along the coast in the vicinity of Nome. They also appeared 3 or 4 weeks later than the Nome species. On entering the 4-passenger plane to return to Nome from the American River country, we found that literally thousands of mosquitoes had entered the plane while we were on the ground. I was disturbed, because I had not brought an aerosol bomb along. Imagine my relief when the pilot reached into a box and pulled one out. The Army had learned the value of these dispensers of insecticides and was using them in far corners of the world.

While in Alaska I tested some repellents that had been developed since our Hudson Bay trials in 1943. The mosquito species were different, but the repellents proved their value once more, and we were happy. In the Alaska experiments with repellents I allowed each volunteer host to treat one arm himself with only the directions on the container as a guide; then, carefully and thoroughly, I treated his other arm with the same repellent. Our data show that, on an average, about 30 minutes' additional protection is gained when the chemical is applied by an experienced worker rather than by the untrained host.

The return trip to the States was by plane over the Alaska Highway from Fairbanks to Great Falls, Mont. En route I stopped for a day or two at each of the several airports and had myself driven in a jeep from 50 to 100 miles up and down the highway in an effort to sample the mosquito population. However, as it was now late in August most of the mosquitoes had died out, so my collections were disappointing.

DISPERSING DDT SPRAYS WITH LARGE AIRCRAFT

As the war progressed westward in the Pacific, the need for a modern means of controlling mosquitoes over large areas became urgent. Malaria and dengue were taking a tremendous toll of man-days. DDT, although not proven under practical conditions, showed much promise. Amazing stories from our Orlando laboratory began to appear in 1943 (2) regarding the effectiveness of this new insecticide. Under test conditions, at least, a material that could be applied from aircraft was killing mosquitoes and their larvae in a single application (12). Preliminary tests (4) on a small scale in the Florida salt marshes had produced excellent results. Special equipment was soon designed for spraying DDT from various types of aircraft. In April 1944 A. W. Lindquist and W. C. McDuffie (7) demonstrated in Panama the possibility of killing adult mosquitoes in dense jungle with DDT by use of small Navy aircraft equipped with devices designed by C. N. Husman.

Over large jungle areas these small planes were inadequate because of their small pay loads. We began thinking in terms of large aircraft. Soon an Army project was set up for experimental spraying from a C-47 with a capacity of 800 gallons and a B-25 with a capacity of 550 gallons. Army engineers designed special dispersing equipment. The tests were to be conducted over typical jungle in Panama.

In January 1945, 18 of us flew to Panama from Orlando by way of Texas, Mexico, and Costa Rica in the two Army planes that were to serve as our spraying machines. Together with two four-man Air Forces crews our party included four officers and one enlisted man of the Army, a chemical engineer from the University of Illinois, and four Department of Agriculture entomologists.

Delayed by weather and by regulations, the flight took $4\frac{1}{2}$ days. Because we were flying by contact and had to remain low enough to sight landmarks, we bumped along slowly, in steadily rising temperatures. On the other side of the fuselage from our bucket seats were eight 100-gallon fabricoid tanks stacked in front of windows. Part of the floor of the plane had been removed to make room for the discharge pipes leading to the cut-off valve. Sitting on our parachutes placed us too high to see well out of the windows, but all in all it was an interesting trip.

The Army had invested an immense amount of labor in preparing the test plots where we were to make the experiments. Six plots were laid out, each 1 mile long and $\frac{1}{2}$ mile wide. They had to be separated from each other by about $\frac{1}{4}$ mile so that a spray could not be carried from one plot to another by wind. Connecting the plots were well-defined trails; around them and through them in crisscross arrangement similar trails had been cut—through dense jungle. Such trails were necessary because of the rough terrain, the dangerous black spines borne by palms of a certain species, and the possibility that personnel might become lost. Stakes had been set at regular intervals on the plot boundaries and diagonals. As a result any of us could always locate himself and go directly to and from his appointed station without undue loss of time.

Several sheets were spread on the ground within each plot that was to be sprayed. This enabled us to count the insects that fell at 2-, 4-, and 24-hour intervals after the spraying and identify them as to species. Most of the species of insects were represented by only 1 to 5 specimens each, but in the *Diptera* various species of *Calliphoridae*, *Sarcophagidae*, *Tylidae*, and *Culicidae* were obtained in much larger numbers. More than 50 individuals of each of several mosquito species and more than 200 individuals of one were recovered. Specimens found on the sheets represented 53 species of *Coleoptera*, including 16 species of weevils, and 148 species of *Diptera*, including 10 species of blowflies (14).

Casual observations of the insect populations in the jungle indicated no change in number or species of insects other than mosquitoes after treatment. Occasionally large *Lepidoptera* and *Hymenoptera* showing characteristic DDT poisoning were seen on the ground soon after treatment.

The Signal Corps of the Army provided a ground-to-plane communications system, which enabled occupants of planes to keep in constant contact with men on the ground as they applied the sprays. Smoke bombs and balloons were used to indicate plot boundaries to men in planes.

For estimating the mosquito population, we decided upon two methods. The first was for 20 teams of 2 men each to count in each

plot the mosquitoes landing on them in a 2-minute period at dusk and another at dawn. Twice daily for about 5 days before the plots were treated and for 14 days after treatment trained members of the Medical Corps made such counts. The well-defined trails and labeled stakes made it easy for these men to find their stations, where they promptly began counting mosquitoes when a signal gun was fired. A total of 5,501 man-days were employed in preparing for and completing the tests. The second method was use of stable traps. A modified stable trap of a design conceived by E. H. Magoon, of the Rockefeller Foundation, was placed in the center of each of the plots. Several times before the spraying was begun we placed a Panamanian pony in each trap at dusk and next morning counted the mosquitoes that had been caught in the trap during the night. On the morning of our first trial, the stable trap in the plot that was to be treated contained so many mosquitoes that an actual count was impossible. The estimate agreed upon was 10,000. The mosquitoes were allowed to escape. Thirty minutes later a B-25 roared overhead spraying a 5-percent DDT fuel-oil solution at the rate of 2 quarts per acre. Next morning some 30 of us—Army medical officers, entomologists, technicians, and others—left Panama City at 4 a. m. and were at the stable trap before daybreak. With the aid of flashlights we peered into the trap to see how many mosquitoes had turned up to feed on the pony the night after spraying. We located just 1. The counts were continued for about 2 weeks and the numbers of mosquitoes rose slowly to 200 during that time. The numbers of mosquitoes recorded in one plot left untreated were then compared with the numbers recorded in the five treated plots.

For the first time, specific data were available on the effectiveness of DDT spray applied at a known rate upon a population of *Anopheles*, *Mansonia*, *Aedes*, and *Culex* adults. It appeared that within 24 hours we had reduced by more than 99 percent the adult mosquito population within an area of dense jungle 1 mile long and $\frac{1}{2}$ mile wide. With that kind of result there was every reason to believe we could control the spread of malaria, dengue, or any other mosquito-borne disease within a matter of hours.

Before the treatment, members of the Army School of Malariology, C. Z., had put in several places on the ground small buckets of water containing *Aedes aegypti* (L.) larvae. Twenty-hour hours after the treatment, 70 to 90 percent of these larvae were found dead. Some of the buckets had been placed under heavy or wide-spreading leaves, but this protection had not saved the larvae. The results seemed really too spectacular; some of the experimenters were skeptical of them until subsequent tests gave approximately the same results.

Two or three weeks after these tests we sprayed an isolated section of Gatun Lake and the adjacent shore line from a B-25. *Anopheles*

albimanus Weid., an efficient vector of malaria in Panama, likes to breed in large unshaded bodies of water where the mosslike aquatic plant *Najas* comes to the surface. This plant forms a mat of vegetation that protects the larvae from wave action and from predaceous fish. In preparation for the Gatun Lake test such an area was found, several acres in size. Technicians from the Army School of Malariology took 200 half-pint samples of water from the "breeding ground" and reported an average of a dozen mosquito larvae per sample. A stable trap was set up on the adjacent shore line and baited with a pony. At dawn of the day when the B-25 was to put out, several officers and others visited the trap and estimated that about 15,000 mosquitoes had been caught, about half of them *Anopheles albimanus*. The pony was then taken out of the trap, the mosquitoes were liberated, and the signal was given for the B-25 to put out the spray. Five-percent DDT oil solution was applied at the rate of 2 quarts per acre. That evening the pony was returned to the trap. The next morning we found 86 mosquitoes in the trap and found not a single larva in 200 samples of water. Again, the kill appeared to have been more than 99 percent (13).

The Army and Navy lost no time in getting this new technique out to the islands of the Pacific. Thereby a great deal of suffering on the part of our troops was prevented and many, many man-hours were saved that would otherwise have been lost to the war effort.

Our tests yielded valuable information on the kinds of weather conditions that are favorable for spraying and on the desirable size and distribution of particles of the different sprays. An Army officer trained in biochemistry devised an ingenious method for collecting droplets of the spray at 10-foot intervals of elevation from the ground to the tops of trees about 125 feet high. He tied several large balloons to the end of a stout cord, and at 10-foot intervals along the cord he secured petri dishes in which glass slides had been fastened. Each glass slide was covered with magnesium oxide. The pattern of the pink- or blue-tinted spray was easily seen on the white-coated slides. The size of the DDT particles and their distribution were recorded. From this information we could check the amount of spray dispersed per acre.

DDT RESIDUAL SPRAYS IN MEXICO AGAINST ANOPHELES PSEUDOPUNCTIPENNIS

It was suggested by A. W. Lindquist and others of the Orlando laboratory that malaria might be controlled by spraying DDT on the walls and ceilings of dwellings and farm buildings. Laboratory tests of pyrethrins against bedbugs by Lindquist and associates in 1942 demonstrated the soundness of the residual principle and the feasibility of malaria control with residual treatments employing

DDT. Field tests by J. B. Gahan (5) in that year against *Anopheles quadrimaculatus* Say at Tallahassee, Fla., and Stuttgart, Ark., demonstrated reduction of adults by at least 91 to 99 percent and of larvae by at least 57 to 63 percent. The desirability of treating all the dwellings in a highly malarious district became evident. A satisfactory location near Cuernavaca, Mexico, was suggested by George C. Payne, of the International Health Division of the Rockefeller Foundation. We liked Dr. Payne's suggestion because the malaria vector in that locality was a different species of *Anopheles* and we were eager to learn whether all species were equally vulnerable to DDT residual or surface sprays. In the Cuernavaca area this anopheline breeds almost exclusively in the rice fields, therefore the larvae are restricted to well-defined areas. Several small Mexican villages a few miles west of Cuernavaca seemed to offer just the combination of conditions we were looking for—a new species of anopheline with restricted breeding habits, an impoverished community, and lots of malaria.

Early in February 1945 J. B. Gahan (3) was detailed to go to Mexico and, with the cooperation of the Rockefeller Foundation and the Mexican Department of Health, treat two villages with a DDT spray. Two nearby villages were to be left untreated as checks.

In April and May a 5-percent DDT water emulsion prepared from a concentrate containing 25 percent of DDT, 68 percent of xylene, and 7 percent of Triton X-100 was applied to dwellings at a rate of about 1 gallon to each 1,000 square feet (about 200 mg. of DDT per square foot). This work was well done by two trained and responsible Mexican technicians under the daily guidance of Gahan. The houses sprayed had walls of adobe, stone, wood, brick, straw, and cane. The relative abundance of *Anopheles* larvae in the treated areas and in comparable untreated areas was determined from samples of water dipped in the adjoining rice fields.

The numbers of adult mosquitoes found in the treated villages after May were never more than 2 percent of the numbers found in the untreated communities and were usually less than 1 percent, indicating reductions of more than 98 percent. Assuming that a treated village and an untreated one used for comparative purposes would have had about the same mosquito populations had no sprays been applied, we can say that the DDT residues reduced the number of larvae at least 85 percent throughout a 4-month period. However, if an adjustment is made for a difference actually found between the two villages before the spraying was started, the decrease is calculated as 94 percent.

I flew to Mexico City in September 1945 (15) and spent a month observing this project just before the work was closed down for the season. Mr. Gahan and his Mexican assistants easily proved to me the striking scarcity of adult mosquitoes in the villages that had been treated and of anopheline larvae in the adjoining rice fields, in com-

parison with their great abundance in nearby villages and rice fields where the sprays had not been applied.

The reduction of malaria during the first season was difficult to estimate because of the manner in which notifiable diseases were recorded. Now, however, after 3 years of treatments, we are justified in claiming a great reduction in numbers of anopheline adults and larvae and a significant reduction in incidence of malaria. Also, the families whose dwellings were treated have been blessed with reductions in numbers of flies, fleas, bedbugs, cockroaches, and other unwelcome insects.

THE USE OF A WETTABLE DDT POWDER IN THE TROPICS

The early formulations of DDT included solutions, dusts, and oil concentrates, the last-named intended for dilution with water to make an emulsion. Each had its advantages and disadvantages. There remained a need for a spray that could be used without creating a fire hazard and one that could be used safely on animals.

In 1945 there appeared new products in powder form containing various amounts of DDT. These powders contained a wetting agent, which made them compatible with water and permitted them to go into suspension. Sprays made of wettable DDT powder might be used on foliage, on the surface of buildings, and on animals without absorption. They certainly would offer no fire hazard. But would they kill insects? Preliminary tests in the laboratory indicated effectiveness equal to that of the emulsion and solutions, although the action tended to be less rapid.

In December 1945 a medical officer of the Aluminum Co. of America called at our office to inquire whether there existed a DDT product that could be used on dwellings of thatch and rough lumber without creating a fire hazard. The company wanted to treat the dwellings of its employees in two bauxite mining villages in Surinam (Dutch Guiana), South America, as part of its program of sanitation and malaria control. We told him that wettable DDT powders were available but that we had no precise information indicating whether they would be effective; that the new formulations looked good but should be tested on a practical scale by someone experienced in the use of residual sprays and in control of mosquitoes and malaria. I could see the possibility of an excellent research project through which the company might obtain the information it sought and the Bureau of Entomology and Plant Quarantine might obtain information that would be useful to our military forces and also to our civilian population across the United States. A cooperative agreement was signed by officials of the Aluminum Co. of America and the United States

Department of Agriculture, and early in March 1946 I flew across the Caribbean again, this time to Surinam.

It would be hard to imagine a more intriguing place in which to carry on mosquito-control research. In Surinam several peoples from the Eastern and Western Hemispheres live side by side without losing or greatly modifying their identifying customs, speech, or religion, and malaria, filariasis, dysentery, leprosy, and other communicable diseases are common.

Primitive peoples live there. I have been told on good authority that far in the interior, near the Brazilian border, a tribe of red men still lives in the stone age, without benefit of fire. The aboriginal Indians belong to the Carib, Arawak, and Warau linguistic stocks. They are mostly of pure stock and live in the interior. Bush Negroes, or Djoekas, live on the upper reaches of the rivers but not so far inland as the Indians. The Djoekas are of pure African origin and are descendants of slaves brought to the colony 200 to 300 years ago. Among these peoples the malaria rate is high (17), but I saw no cases of filariasis among them. Javanese and British Indians were imported 50 years ago as labor. For the most part they remain true to their customs, religion, and race. The typical native Surinamers are dark-skinned but have considerable white European ancestry. Among these people filariasis is common and malaria epidemics have been serious. A few Chinese storekeepers live in the colony.

Moengo, the mining village where the test was made, is a little paradise 120 miles up the Cottica River from Paramaribo. Its isolation by miles of virgin jungle helped to make it suitable for our experiments. The Aluminum Co. of America had built it according to modern housing standards, and, within certain limits, it was a clean, well-sanitated group of homes. I found that mosquito genera and species were richly represented and that species of *Anopheles* (6), including among others *A. pessoai* Galvao and Lane, *A. aquasalis* Curry, and *A. oswaldoi* Peryassu were breeding largely in the rice paddies cultivated by the Javanese. The common house mosquito, *Culex quinquefasciatus* Say, was breeding by thousands in the water of moats surrounding the foundations of the houses. These moats were supposed to be cleaned at regular intervals, but apparently there had been "misses."

The fly problem was rather severe. Within a few hours I easily found the source, at a farm about a mile from the center of the village. There were two cow barns, in which some 60 head of milk cows were fed and were kept under lights at night as a protection against vampire bats. In an effort to conserve manure the stables were cleaned only once in several weeks. Each morning a fresh layer of green grass was spread over the manure that had been deposited the night before. The fermenting compost served as an excellent medium for breeding of

house flies. Horn flies, also, were present in great numbers on all the farm animals.

I had brought two kinds of DDT with me. A ton of a 50-percent wettable DDT powder was for use as a 2.5-percent water suspension on most of the houses and barns made of thatch and rough lumber and elsewhere on surfaces where the white deposit would not be objectionable. This spray was also used directly on the milk cows and on a few donkeys. Over 90 dogs were dipped in a bath containing 1.5-percent DDT. I had brought along also several hundred pounds of technical-grade DDT. This was mixed at the rate of 7 ounces to each gallon of a refined greaseless kerosene of which 22 drums had been brought from the States. Three wheelbarrow sprayers had been shipped from the States, two motor-driven and one operated by hand. A quantity of flat- or broom-type nozzles, oil-resistant rubber hose, and other accessories came in and were ready for use a few days after my own arrival.

The main problem was to reduce the mosquito population. I had chosen five ways to determine the numbers of mosquitoes before and after treatment. With plans sent to the company several weeks before I left the States, carpenters and mechanics had built three stable traps and a rotary-type trap (1). An extra cone of wire screen had been provided for use on the fender of an automobile. I brought with me a New Jersey light trap. The fifth method was collecting by hand the mosquitoes that landed on two men hired for the purpose. One of these men was a Belgian, an ex-convict from the French penal colony 30 miles distant. The second was a British Indian. The mechanic assigned to operate the rotary-type trap was a Chinese. These men and those assigned to me for applying the spray were willing and reliable workmen, and to them goes the credit for a big job well done.

The rotary trap consisted of two cones of screen wire rotated around a pivot driven by a small gasoline engine. The diameter of the cones was such that each screened exactly a cubic foot of air for every foot it was moved forward. The pivot was synchronized to travel at the rate of 20 miles per hour. The two cones were operated about 3 feet and about 5 feet, respectively, above the ground. An identical cone trap was mounted on the fender of our automobile. By driving this car at 20 miles an hour I could screen 52,800 cubic feet in 30 minutes. The two cones, when operated 30 minutes, screened twice as many cubic feet of air but in one spot about 10 feet in diameter. At the small end of each cone I attached a cloth bag having a bottom of fine screening. As the cones moved forward at the rate of 20 miles an hour the cloth bags were stretched out parallel to the cones. At the appointed time each bag was taken off the cone and placed in a jar containing a piece of cotton saturated with chloro-

form. In this manner I collected a wide variety of mosquitoes and other insects. (On one occasion I caught a bat.)

With the aid of D. C. Geijskes, an entomologist from the Surinam Agricultural Experiment Station, in Paramaribo, I selected five ecological habitats in which to operate the traps: (1) At the cowbarns, in a low pasture closely adjacent to swamp jungle; (2) at the center of the village, high and well drained; (3) in an opening in the jungle halfway between the village and the rice-paddy section; (4) in the midst of the rice-paddy section; and (5) 3 miles distant at the edge of a Djoeka village. In the fifth environment, it was found, the cone traps could not be operated.

The first week, I collected as much information as I could on the mosquito, fly, tick, flea, bedbug, and cockroach populations. Then I began spraying the houses, outbuildings, and cattle. I started with the cowbarns and cattle first in an effort to reduce the number of flies that were finding their way to my dining table nearly a mile distant. Every square foot of walls and ceiling of dwellings and outbuildings was sprayed. Within a few days the fly nuisance was no longer a problem. Horn flies and houseflies were actually difficult to find.

Various tests demonstrated the effectiveness of the new DDT formulations against mosquitoes, cattle ticks, chigoes, fowl ticks, cockroaches, bedbugs, and other insects (19). A sheet of white paper 1 yard wide and 2 yards long laid down in the corner of a cool, sheltered garage was examined daily for dead mosquitoes. Every day several mosquitoes that had come in contact with the DDT-treated walls fell on this paper. Over 900 mosquitoes were taken in a light trap overnight before the village was sprayed. Beginning 2 or 3 weeks later, for several months this light trap caught only a few dozen mosquitoes at most. All the collecting devices in three of the stations showed a marked reduction of mosquitoes. At the fourth station, in the clearing halfway between the village and the rice paddies, there was no reduction of mosquitoes; here there were no buildings, no cattle, and consequently no DDT applications within several hundred yards of the collecting devices. The few data we obtained on the numbers of mosquito larvae in the rice fields did not indicate any reduction. The most positive control of mosquito larvae with the wettable DDT powder was in the moats around the pillars of the houses. As nearly as I could evaluate the control here, the eradication of *Culex quinquefasciatus* larvae was 100 percent and remained so when I revisited the village 10 months later.

I returned to Moengo to evaluate the DDT treatments in January 1947. Some of the results were beyond our fondest imagination.

The nuisance of mosquitoes in the village was gone. In the rice-paddy area they had been absent from the dwellings for several months but were being noticed again. An offer of cash for living bedbugs found no takers. Horn flies and the fowl tick, as nearly as I could determine, were eradicated. Cockroaches were not eliminated, but the previous population of the American cockroach appeared to have been reduced about 90 percent. In March 1946, after spraying one house I counted some 550 dead ones. In February 1947, after spraying this house again, I counted 49, most of which were immature individuals. Ticks on the cattle were greatly reduced but were not eradicated by any means. (The cattle had been sprayed each month from March 1946 to February 1947.) All evidence indicated a 100-percent reduction of chigoes breeding under the houses in the crushed bauxite.

The most convincing evidence of the effectiveness of the wettable DDT powder was obtained in the house in which I lived during my first visit to Moengo. The walls and ceiling were sprayed with a 2.5-percent suspension of the new formulation, although such treatment leaves an unsightly white deposit. The house next door was sprayed at the same time with the 5-percent DDT oil solution. Bimonthly reports coming up from Surinam showed that the wettable powder treatment remained effective longer than did the oil solution. One of the first tests I made on returning to Moengo in 1947 resulted in capture of 4,000 to 5,000 living mosquitoes in a stable trap. Half of these were placed in each house one morning at 9 a. m. Sheets had been laid on the floor of each house, along the walls and in the corners, to catch the mosquitoes, if any, that fell. At 5 that evening we reentered the houses. Where the wettable DDT powder had been used, we found hundreds of dead and dying mosquitoes on the sheets but none that were able to rest on the walls. Ten months after application in a hot and humid climate, this potent insecticide was still killing mosquitoes. In the other house we found dozens of mosquitoes that showed signs of DDT tremors but also hundreds on the walls that appeared well and healthy. Fifty hours later I saw two living mosquitoes there that appeared not to have been harmed.

The crowning piece of evidence that DDT had really taken hold in Moengo was delivered to me by William Asgerali, the British Indian boy who had been assigned to me on my first visit there. Bill took care of the traps and counted the mosquitoes during the months between my visits to Surinam. He was my interpreter, guide, technician, and faithful friend. When I stepped off the boat at Moengo in January 1947 he greeted me with "Mister, one of the Djoekas named their baby boy DDT" (18).

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1. Technicians in the muskeg country of northern Manitoba, Canada, must be well protected by heavy clothing and head nets against the mosquito hordes.



2. Mosquitoes by the hundreds would ride on our backs as we marched through the wilderness adjacent to Churchill on Hudson Bay.



1. Counting mosquitoes on different colored shirts, Churchill, Hudson Bay.
"Barebacks" were also attractive bait.



2. The author applying mosquito repellents to legs and arms of volunteers in Alaska to evaluate the most effective materials. (Photograph by Signal Corps, U. S. A.)



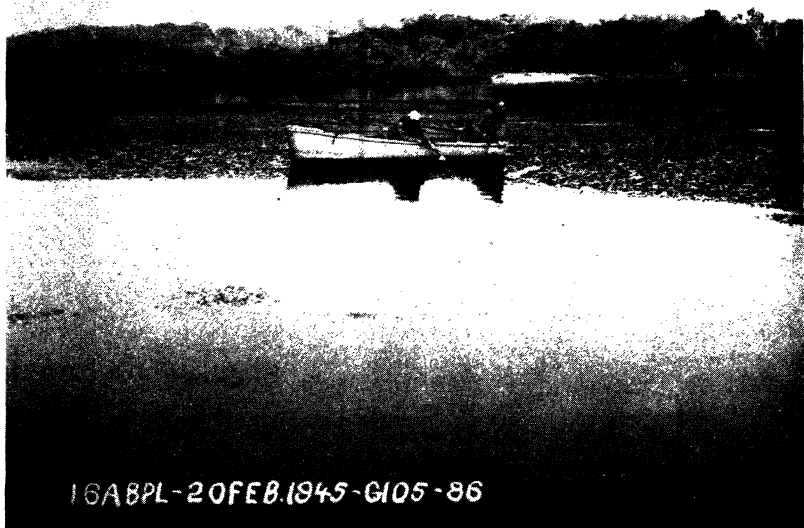
1. Flying from Seattle to Alaska we passed over the 9,000-foot St. Elias Range and the source of some of the coastal glaciers.



2. The B-25 applying the 5-percent DDT spray over the Panama jungle. (Photograph by Signal Corps, U. S. A.)



1. Leaves showing good coverage of droplets of DDT spray even in the lower elevations of the jungle. (Photograph by Signal Corps, U. S. A.)



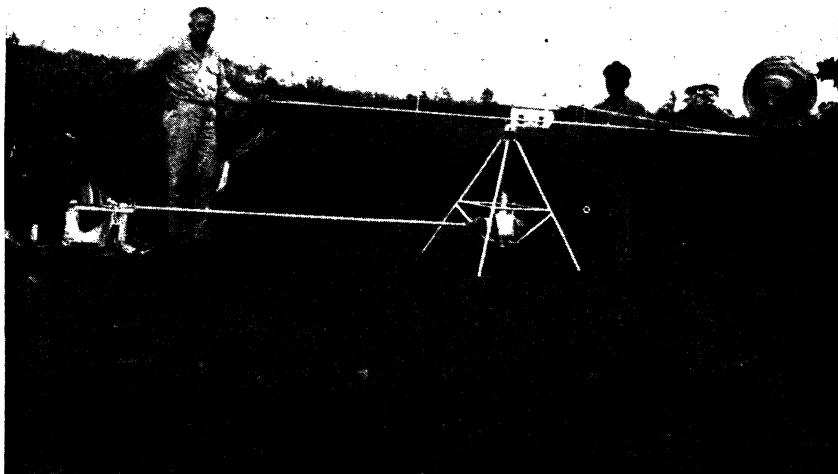
2. *Naias* bed in Gatun Lake, Panama, where a dozen *Anopheles albimanus* larvae were taken in each of 200 samples before treatment with DDT. Twenty-four hours after treatment not a single larva could be found.



1. Mexican technician spraying DDT on thatched homes near Cuernavaca, Mexico.



2. Moengo, Surinam. Practically every square foot of surface of these buildings was sprayed with a 2.5-percent wettable DDT powder.



1. Rotary-type trap as used in Moengo.



2. Cone trap mounted on the fender of an automobile as used in Moengo.



1. The author's house in Moengo, Dutch Guiana. The apartment in this house, sprayed with a 2.5-percent wettable DDT powder, killed mosquitoes 10 months after application.



2. An example of a perfect deposit made with a wettable DDT powder applied to a wall surface. Droplets are large, coverage thorough, with no running of liquid.



1. A Djoeka couple of Surinam.



2. A Djoeka village in Dutch Guiana.

THE PRIMARY CENTERS OF CIVILIZATION

By JOHN R. SWANTON

Collaborator, Bureau of American Ethnology

If civilization is produced, or induced, by biological factors, factors in the natural environment, or factors in the cultural environment, a study of the several centers where it originated may enable us to isolate these and use that knowledge for the benefit of the race.

But at the outset it is somewhat difficult to determine the exact number of cultural or civilizational centers with which we have to deal since the archeological survey of our globe is still incomplete. Yet certain general statements may be made. Taking the Eastern Hemisphere first, it would be pretty generally agreed that one such center existed in Egypt, a second in the Tigris-Euphrates Valley, and a third in the valley of the Indus, while most would probably be willing to add a fourth, in northern China. Elsewhere in and near the Iranian Plateau, however, in Syria and Asia Minor and in the island of Crete there were higher cultures of an antiquity nearly as remote. The site of Anau north of the Elbruz has shown a series of archeological types which seem to parallel in antiquity those of India and the twin rivers, and almost as much may be said for the remains in Crete. This last center, although undoubtedly dependent on the cultures of Egypt and Asia, shows from an early age such esthetic maturity as to incline one to give it semi-independent position. As to the rest, it is clear that although they pursued in the main an independent course of development, they yet influenced one another at times in a very marked manner. This is not so evident in the case of China, but sinologists generally hold that China was in its beginnings subject to strong influences from the west.

In the New World we have another series of centers lying, as in the case of the Old World, along the main mountain massif of the continent and not far from its center. Here, however, it would be generally agreed that two stand out above the rest, in Central America and in Peru, although there were a number of secondary foci and these two centers themselves show considerable complexity.

In the present study of these several culture centers we shall have

to leave largely out of consideration that represented by Anau which calls for more supporting material as the survey of northern Iran is pursued by undertakings like that of Krogman on Tepe Hissar.

To begin with the westernmost of our centers, Crete (although admitting that it is doubtfully entitled to a primary position), we find it generally agreed that the physical type of its inhabitants was what has been called Mediterranean, dark and dolichocephalic. This was partially displaced and its culture overthrown by a brachycephalic, Armenoid type connected with the Alpines of Europe. These brachycephalic people constituted one of the chief Greek strains, and the partial substitution of one for the other shows that both are capable of supporting high civilizations.

Most of the ancient Egyptians were dolichocephalic. The brain cases of the predynastic Tasians and Merimdeans are said to have been wide. Those of the Badarians, Amratians, and Natufians, who succeeded them, were narrow. The Badarians are also said to have had just a hint of the Negroid or South Indian about them. In the dynastic period a larger and more robust but still dolichocephalic type makes its appearance in the royal tombs, and during the epoch of the third dynasty a brachycephalic Armenoid type becomes prominent among the upper classes. Petrie distinguishes as many as six racial types among the enemies and followers of Menes. The earliest Sumerian skeletal remains suggest a long-headed type, and two long-headed types have been found at Kish, but at that site there also appear Armenoids. These last were probably contributed by the Hurrian or Japhetic population. Our knowledge of the physical types connected with the Indus culture is thus summarized by Childe:

The population of Mohenjo-daro was certainly mixed; the skeletal remains and figurines undoubtedly belong to several physically distinct types. At the bottom of the social scale came a primitive Australoid stock; the thick lips and coarse nose of a little bronze statuette disclose at once the kinship of this group to the surviving aboriginal tribes of Southern India and the position which it, like its modern representatives, occupied in the community. A higher type, long-headed like the last, has been termed Eurafrian or even Mediterranean. It seems to approximate to one of the long-headed Sumerian types and the similarity is accentuated in the portrait statues by the beard, shaven upper lip, and long hair done up in a bun behind quite in Sumerian fashion. Thirdly, a brachycephalic Alpine or Armenoid type is represented as at Kish in Akkad. Finally, a single skeleton and several clay figurines belong to undoubted Mongols or Mongoloids, the earliest dated examples of this racial type yet detected.

It is a fair guess that the people mainly responsible for Indus civilization were Eurafrians, and if we are to associate vitality as civilization producers with physical type, the dolichocephalic people usually called Mediterraneans would seem to have most of the facts in their favor since they vastly predominated in Crete, in Egypt, at the head of the Persian Gulf, and probably in the Indus Valley. How-

ever, the circumstance that a brachycephalic, Armenoid type makes its appearance in Egypt in the Third Dynasty and "in the upper classes," the greater significance now attached to the Hurrian broad-heads in the Tigris-Euphrates Valley and the fertile crescent as a whole and the neighboring highlands, including the Hittites, the pronounced brachycephalic element among the Indus people, and above all the attainments of the brachycephalic Greeks, indicate just as clearly that they were perfectly capable of taking over a high civilization and even, as in the case of Greece, improving upon it.

Whatever doubts may remain as to the abilities of brachycephalic people as discoverers and inventors are removed, however, when we turn to the remaining centers of civilization. The Chinese are among the most typically brachycephalic people in the world. There are and have been from a remote period dolichocephals in eastern Asia, but evidence is as yet lacking that they originated Chinese civilization. In the New World, at any rate, the higher cultures are decisively associated with brachycephaly. The Maya may be mentioned at once, and in the secondary culture areas along the Mississippi Valley and on the North Pacific coast brachycephaly is very prevalent. It is again markedly in evidence among the Quechua and other advanced tribes of northwestern South America. On the other hand the hunting peoples of northeastern North America and eastern South America usually are dolichocephalic. The conclusion seems evident that head form, pathological cases aside, has nothing to do with cultural status. Indeed, if that were the case, artificial head-deformation, which often distorted the occiput vastly more than nature varied it, should have had a more marked effect on the intelligence of tribes which practiced the custom. On the contrary, many of them, such as the Aymara, Maya, and Natchez, were among the more advanced peoples.

Nor do we find, allowing for the later date of those in the New World, any marked differences between the several culture centers when we compare their contributions to civilization. Emmer wheat was cultivated by the Egyptians, and bread wheat by the Sumerians of the Tigris-Euphrates Valley. Both also had barley. Wheat and barley were cultivated by the Indus people and they may have raised rice which, in any case, originated in India or China. The great American contribution to the staple cereals was corn, and they also gave us various species of beans and squashes. Olive culture is thought to have started in the eastern Egyptian delta, but on the other hand the Sumerians and Indus people cultivated the date palm. Flax was raised by the Egyptians and Sumerians, cotton by the Indus people, Maya, and Peruvians, and the Chinese contributed silk to the textiles of the world. Cattle, sheep, and swine were already domesticated in Egypt in predynastic times and apparently in the earliest period in Sumer. Humped and humpless cattle, buffaloes, sheep, fowls, and

elephants were domesticated by the people of the Indus who seem not to have had swine. Asses were also known in Egypt and Sumeria from a remote period, but horses were introduced from Central Asia much later and were taken up most enthusiastically by the people of the two rivers. In this particular the New World was much behind the Old. Nearly all of its tribes including the Maya had dogs, but they were of very limited utility. The Peruvians with their herds of llama and alpaca were somewhat in advance of the rest.

Stone masonry was, of course, further developed in Egypt than in any other Old World center except Crete, the Sumerians and Indus people depending on brick. In the New World the Peruvians were by all odds the best masons. Copper seems to have been known to the Egyptians and Sumerians at an early date, but bronze was employed first by the latter and by the people of the Indus. The Indus people also prepared an alloy of copper and arsenic. In the New World copper was widely known and considerably used, but we do not know where it was first employed. The Peruvians had learned to make bronze, and it is believed to have been invented independently by them though it appears also in Central America.

The plow was independently invented in Egypt, Sumeria, and China, and the foot plow was known to the Peruvians. The potter's wheel seems to have been used earliest in Sumeria and India, and the wheel for vehicles appeared first in these centers or the intervening territory. We apparently owe the true arch and dome to the Sumerians. The invention of glass is attributed to the Egyptians, but the art of glazing goes back to the earliest Sumerian epoch. To China we owe the mariner's compass, block printing, rag paper, paper money, playing cards, porcelain, and gunpowder. To medicine Peru has made two notable contributions, quinine and cocaine. Chocolate comes from Central America; tea, from China or India. Tobacco is again an American product, but we do not know at what center it was first taken over by man. A boat used by the Egyptians in predynastic times is regarded by many as the ancestor of all later ships. Sumerians had discovered at a very early date the principle of the modern ax-head perforation to admit the handle.

The rebus system of writing was evolved independently in all these centers except apparently Peru, where its place was taken by the device of the quipu. Our alphabet comes from Semites, who derived their inspiration, it is generally held, from the Egyptian hieroglyphs. It is also believed at the present time that the Maya hieroglyphs had evolved to the threshold of phonetic representation.

The Egyptians seem to have been the first geometricians, and they led the Old World in the development of an accurate solar calendar of 365 days. Incidentally they gave us our earliest fixed date, 4241 B. C., but the Maya independently, though later, evolved a calendar

equally accurate. The Sumerians and their Semitic successors, on the other hand, surpassed both in astronomy in spite of having associated it with astrology. They identified five of the major planets, and could predict eclipses with a high degree of accuracy. They introduced the use of degrees, minutes, and seconds, divided the day into 24 (originally 12) hours, and the circle into 360 degrees and were the originators of the Zodiac. Breasted states that "the earliest known literature of entertainment was produced in the Twelfth Egyptian Dynasty, 2000-1788 B. C.," and he also claims for the Egyptians the doubtful honor of having created the first empire in the world, 1580-1350 B. C. Philology apparently received first serious study in India, but that probably did not go back to the Indus culture. The same may be said of Hindu philosophy and religion, though it has been demonstrated that its non-Vedic elements stemmed from the Indus. India is also supposed to have influenced the second great center of philosophy in the ancient world, Greece, through Pythagoreanism, but it is probable that Greece also drew philosophical inspiration from the cultural centers nearer at hand. If we attempt to characterize the governments of the several centers, we may say that Egypt, the Inca Empire, and to a certain extent the Maya impress us as theocratic despotisms, Sumeria as a group of military states, Crete as a trading empire, and the Indus culture as one finding its outlet in communal civic enterprise.

Something has already been said regarding the physical types of the occupants of the several cultural areas. Let us now take a somewhat broader world view of this subject. The first classification of human races to receive wide acceptance was that of Blumenbach into the Caucasian or White, Mongolian or Yellow, Ethiopian or Black, Malayan or Brown, and American or Red. Cuvier reduced these to three: White, Yellow, and Black; and Huxley recognized five: Australoid, Mongoloid, Negroid, Xanthrochroic (yellow-haired), and Melanochroic. Haeckel based his classification on hair texture, and gave the following divisions: Woolly-haired (subdivided into fleece-haired and tufted-haired), and smooth-haired (subdivided into straight-haired and curly-haired). Retzius based his on types of heads and prognathism; narrow heads and projecting jaws, narrow heads and straight jaws, broad heads and projecting jaws, and broad heads and straight jaws. The American anthropologist, D. G. Brinton, set up the following groups: The Eurafrian race (including a north Mediterranean and a south Mediterranean branch), the Austrafrian race (including the Negrillo, Negro, and Negroid branches), the Asian race (including the Sinitic and the Sibiritic branches), the American race, and Insular and Littoral peoples (including the Nigritic, Malayic, and Australic branches).

F. Müller and Latham classified by language and Waitz and Ratzel by progress in culture. These, of course, are not classifications of races at all.

In his classic work on "The Races of Europe" Ripley laid down a trinal grouping for that area which has affected all later studies. These three are the tall, fair, dolichocephalic Nordics centering about the Baltic Sea, the brachycephalic Alpines in the central part of the grand division, and the dark, dolichocephalic Mediterraneans about the sea of that name.

In more recent years Dixon attempted a sweeping change in biological classification by dividing all peoples in accordance with three indices, the length-breadth index, usually called simply the cephalic index, the height of the skull, and the nasal index. Different combinations of these yielded him eight races which he called Caspian, Mediterranean, Proto-Negroid, Proto-Australoid, Alpine, Ural, Palae-Alpine, Mongoloid. His system has had few followers or imitators, the tendency being to return to simpler categorizations more nearly like those of Blumenbach and Cuvier. Thus Kroeber gives us the following: Caucasian or White, Mongoloid or Yellow, Negroid or Black, of doubtful classification Australian; Vedda, Irula, Kolarians, Moi, Samoi, Toala, etc.; Polynesian; Ainu. In other words, we have three great races and a wastebasketful of odds and ends. Some would probably add the Australoid to the three majors, and some would fit all the odds and ends into the three-race pattern, in effect a return to Cuvier. Boas is inclined to make two major divisions of mankind, a Northern Fair and a Southern Dark, and to consider the Whites and Yellows first major subdivisions of the former.

The troubles of would-be classifiers show at least the difficulties attending the attempt, and indicate at once that races do not fall spontaneously and readily into a set of clearly indicated patterns, yet the fact that from two to four somewhat vaguely defined grand divisions can be made out and have been specified by several students shows that there is "something there." It is only when we attempt to draw boundary lines rigidly about them that we get into difficulties.

Now when we come to compare our culture centers with these racial divisions we find that four of the former, Egypt, Sumeria, Crete, and the Indus Valley, fall within the boundaries generally assigned to the White race and one within the boundaries of the Yellow, while the American cultures, once assigned to the Red race, must be added to the Yellow in the more general categorizations. It is noteworthy, however, that all these primary culture areas were tenanted by dark peoples, not by ultrablacks or ultrawhites. Gobineau's preposterous attempt to attribute Central American and Peruvian civilizations to colonization by prehistoric Whites of course has no basis in fact. There was probably a Nordic strain in Greece, but since we know that

Greek civilization received its stimulus from Crete, Egypt, and western Asia, and not from the north, any such strain could have had no significance for the primary civilizing effort. The inhabitants of those three regions belong to the darker subdivisions of the White race, those which approximate in some measure the Yellow peoples of eastern Asia and the Blacks to the south. In a trinal classification four centers, Egypt, Sumeria, Crete, and the Indus, may with the reservations just given be attributed to the Whites; and three others, China, Central America, and Peru, to the Yellows.

If we fall back upon a dual classification, a Northern Light race and a Southern Dark one, the centers of civilization fall within the former. However, any deduction regarding inherent racial ability has to be qualified immediately by the admission that none of these centers was in territory occupied by the ultrawhite subdivisions. All are among darker Whites and among Yellows. In Egypt and the Indus, moreover, we have to admit the intrusion of a Negroid strain.

Apart from the above-noted slight advantage which light strains seem to possess in a dual classification of mankind, we may say that the primary centers of civilization show diversity in physical type, language, and general culture, and that all have contributed to the sum total of human attainment. Moreover, there is evidence of heterogeneity at an early period in the population of these centers and subjection to heterogeneous influences from without. As we have seen, at least two types made their appearance in predynastic Egypt, three at Kish in Babylonia, and three or four at Mohenjo-daro in the Indus Valley. We may add that Egypt lay on the edge of the Hamitic family of languages and had constant dealings with both the Semites and Hurrians, Sumeria lay between the Hurrians and Semites and had constant dealings with the Indus, and the Indus Valley lay between the Dravidians and Aryans with Mongoloids not far to the north. Both of the Chinese culture centers postulated by Eberhard lay where three culture areas came together. In the New World the Maya country was between the Uto-Aztecan peoples—with whom they were perhaps connected—and tribes with cultures following South American patterns. The Peruvian area really contained two cultures, one belonging to the interior and one coastal, the latter, and perhaps the former as well, consisting in turn of several minor centers.

The question thus arises whether human culture in these areas did not respond to influences other than those of race. There were no Blacks or Whites in the New World to affect culture either way. In the Eastern Hemisphere all primary culture centers lie in semiarid areas between 25° and 50° north latitude and toward the center of the land mass of the continent. The fact that they lay far north of the Equator has given rise to the supposition that climate had much to do with their origin. It has been claimed that a temperate climate fur-

nished the necessary stimulation discouraging human energy neither by its enervating warmth nor its paralyzing cold.

Without denying that climatic influences played a part here, attention should be called to one other factor not as yet sufficiently emphasized. This is the possibly relative nearness of the Old World cultural centers to the original home of mankind. It might naturally be assumed that in moving outward from any given center the tribes which went farthest would have least leisure in which to make themselves at home in their environment and build up elaborate adjustments, i. e., civilizations, within it. But when we note that, although the New World was populated at a late period, centers of civilization not much inferior to those in the Eastern Hemisphere had appeared there in a relatively brief section of the human time scale, we are warned against laying too much stress on this particular factor. However, it remains true that Old World civilizations lay in regions where some of the oldest human skeletal material has come to light. Other materials of this kind, including the Piltdown man of England, the remains of early man in South Africa, and *Pithecanthropus erectus*, are remote from these centers, but if a point is selected central to the area determined by them and as nearly equidistant as possible from them it will bring us to southwestern Asia and India. It is, admittedly, much too early to dogmatize as to the earliest home of our race. Asia, Africa, and Europe each has its champions, and at any moment some new discovery may incline the weight of evidence to an entirely unexpected quarter. The only thing that seems reasonably certain is that mankind is of Old World provenience. However, southwestern Asia and India happen to lie about midway of the oldest human remains.

Central Asia has been one of the spots most favored by searchers for human origins. It attained its first prominence as a result of the early studies of Indo-European languages, although of course the speakers of those languages were only a portion of the human race, and in more recent times it has been recognized that the spread of languages and the spread of peoples may follow entirely different paths. Nevertheless, Central Asia was taken up by the biologists, particularly under the stimulus of the late Prof. Henry Fairfield Osborn and his followers, and still exerts a powerful influence among both biologists and anthropologists. It was made to fit very neatly into the wave theories of race movement of such men as Griffith Taylor, and seemed to be strengthened markedly by the discovery of China man.

At this point, however, we may introduce another line of evidence which may have some bearing upon the question. In the evolution of animal forms it is usually assumed that the generalized types preceded the specialized, and that the main stem of evolution consisted of forms retaining the ability to adapt themselves to a greater range of situations than the rest. The specialized forms given off by these

are believed to have continued to reproduce in the environments to which they had become adapted and to have died out if radical changes in such environments took place. Under perfectly uniform environmental conditions it might be assumed that new species, genera, families, orders, and so on would spread wave-fashion from this center, but external conditions introduce modifications in any theoretical pattern so that considerable samples of these forms are found from center to circumference. In numerous cases, in fact, earlier and later forms persist in the same environment. In large areas like continents we should expect differentiation to extend over considerable areas and to bear some relation to the completeness of the separation between continent and continent and the time when such separating occurred.

In volume 5 of Bartholomew's Physical Atlas the following zoogeographical provinces are indicated, based upon earlier work by a number of students and valid in the main today :

The Palaearctic region, including all of Eurasia except India, Indochina, and southern China ; the Ethiopian region, including Africa south of the Sahara and southern Arabia ; the Oriental region, including nearly all of India, Indochina, southern China, and the nearer East Indies ; the Australian region, including Australia, Tasmania, New Zealand, the East Indies from the eastern end of Java to the Solomon Islands, and Polynesia ; the Nearctic region, including all of Canada, Alaska, the United States, and northern Mexico with a tongue of land down the Mexican highlands to the Isthmus of Tehuantepec ; and the Neotropical region, including the rest of central and southern Mexico, Central America, and South America.

It is undoubtedly significant that the number of these regions is exactly equal to the number of grand continental divisions, and in some cases at least we can account for their differentiation by the isolation of the continent in question at a particular period in its history. Thus the Australian region owes its peculiar land fauna to the fact that it was set apart from Asia by the Wallace Deep shortly before the appearance of placental mammals. Considerably later South America was separated from North America by the submergence of the Panamanian section, although North American fauna intruded into it when union was reestablished. Again, the fauna of North America is known to resemble that of the Palaearctic region owing to the existence of a land bridge which persisted to a much later period than the Central American isthmus. The African region has been differentiated from the Palaearctic in part by the interposition of the Mediterranean but still more by the sea of sand which we call the Sahara. Farther east the Palaearctic and Oriental regions have acquired their differences in part owing to the interposition of the Indian Ocean which once extended entirely through to the Arctic and in part by the great deserts of central Asia which succeeded.

The two last-mentioned regions and the African region very nearly come to a corner in southwestern Asia, the African extending as far east as Oman while the Oriental region includes the Indus Valley. The Iranian Plateau intervenes as a tongue of the Palaearctic, and separates not merely the Ethiopian and Oriental regions but many related stocks of the higher fauna as well, including civets and ichneumons, chevrotains, pangolins, false vampire bats, elephants, wild asses, buffaloes, lemurs, and Old World monkeys. Particularly it severs the present habitats of the anthropoid apes, man's nearest relatives. This fact indicates some intermediate point as a probable center of distribution, and has given rise to the hypothesis of a former continent in the Indian Ocean which has been called Lemuria since the segregation of the lemurs is particularly striking. Without creating a new continent, I think economy of movement calls for an intermediate center of origin. If our areas were ranged concentrically, we should be justified in supposing that the one on the periphery was the oldest and that nearest the center the youngest, and this is measurably true of the Australian and New World regions, but the three others are placed radially and not concentrically. A center in western India or southern Iran would therefore be nearest to the greatest number of organic forms and involve the least motion in bringing them to their present habitats. We might imagine one genus to have originated at one end of their later habitat and spread lineally to the other, but to suppose two to have done the same thing and to have covered practically the same territory moving in the same direction would be less likely; with three, four, or more the unlikelihood increases rapidly. And if the region indicated gave rise to the higher animal forms, the argument is good that the same was the case with mankind.

Culture centers need not necessarily have arisen near the very spots which witnessed the birth of mankind, but relative nearness to that spot is to be expected. Another argument for southwestern Asia, however, is the fact that cultures are apt to appear where peoples are subjected to a variety of environmental influences or to racial admixture. Thus, the high spot in the aboriginal Northwest Coast culture in America came just where racial and linguistic diversity was most pronounced. The same was true of Southeastern culture, and we have to remember that the Pueblo culture of our Southwest existed among people belonging linguistically to four distinct stocks. Similarly we find that the Maya lay between cultures and languages which are distinctly North American and others clearly connected with South America. Incaic, and the earlier Tiahuanacuan culture arose side by side with two or three somewhat diverse coastal manifestations. We may add that the Maya also lived very nearly on the boundary between the Nearctic and Neotropical biological regions and that two of the principal subregions of the latter, the Brazilian and Chilean, are

bounded by a line cutting through Peru and Bolivia from north to south.

Returning to the Old World we note that the boundary between the Oriental and Palaearctic regions cuts directly through the Indus cultural center and that the boundary between the Palaearctic and Ethiopian regions crosses the Nile close to Upper Egypt. The Sumerian, Cretan, and Chinese centers lie considerably north of the southern boundary of the Palaearctic zone in the general map of Bartholomew, but on the maps of some zoogeographers they lie much closer.

CONCLUSIONS

From the foregoing discussion it appears that the higher civilizations have made their appearance and have spread among peoples of varying physical types and that these centers have contributed to the higher culture of mankind in about equal measure. If the races are ranged in a dual category, Northern Fair and Southern Dark, the centers of civilization fall within the former as usually defined, but in all cases among marginal peoples, not far from the boundaries of the darker races. If it is true that no primary center of civilization arose among the ultrablacks, it is equally true that none arose among the ultrawhites. In one or two of these centers, moreover, there was a black strain at a very early period. Some of these centers—Egypt, Sumeria, the Indus—show early evidences of considerable heterogeneity, and all of them signs of trading contacts with the outside world.

There is thus evidence that factors other than race were responsible for the position of these cultural centers. All of them show signs of contact, and none of those in the Old World, except the one in China, is far from the Plateau of Iran where three of the principal zoogeographical areas come together. This would seem to be a natural point from which life forms spread as indicated by their present geographical distribution. Although skeletal remains of primitive man have been found at widely separated points very far from the region under discussion, it is a fair question whether the distribution of animal life may not indicate the actual center more accurately, and that there is reason to look for the great cultural centers of mankind in the same general territory.

A summary of the foregoing discussion would result about as follows:

1. The primary culture centers lay among people of both dolichocephalic and brachycephalic head form and among those who were intermediate in pigmentation.
2. They were in warm temperate latitudes.
3. They were in areas containing heterogeneous populations or close to areas of divergent cultures.

4. Their contributions to civilization were fairly equal, allowing for the distance which separated American civilizations from the rest and the consequent handicaps under which they labored.

5. The centers in both Old and New Worlds lay near the central portions of the continents and close to the main mountain chains.

6. The Old World centers (except perhaps that of China) lay near the junction point of the three most important zoogeographical areas north of the Arabian Sea and rather distant from Central Asia, the favorite racial homeland of so many theorists.

7. These centers of civilization apparently depended on factors other than those of race.

THE RYUKYU PEOPLE: A CULTURAL APPRAISAL

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[With 5 plates]

INTRODUCTION

As United States forces conquered island after island in the Pacific, hitherto obscure peoples suddenly became headline news. Such a people were the Ryukyuans who were living a simple agrarian life as vassals of the Japanese on a chain of small islands between southern Japan and Formosa. But with the invasion beginning March 27, 1945, the islands, especially Okinawa, became household words overnight. After organized Japanese resistance ceased, following 82 days of bitter fighting, Okinawa and the Ryukyus left the headlines. Since the Japanese surrender, Okinawa continues to be important as one of the reduced-status bases in the Pacific retained by the United States. Currently the civil affairs of the Ryukyu people are administered by the United States Army Military Government.

In view of our interest in the Ryukyus, we have summarized available information on the native people from earliest times to the present. We have attempted to relate the natural environment of the islands and the long history of foreign influence to the native way of life up to World War II. Thus we hope to show not only what the native life was like but how it came to be that way. To complete the picture we have considered the impact of World War II and the effects of the American occupation upon the islanders.

This has not been easy. The archeology of the Ryukyus is little known, and the early written records usually show either a Chinese or Japanese bias. Satisfactory racial and cultural studies of the

Ryukyus do not exist. Although many Americans have observed the war's effect upon the Ryukyans and their culture, no one has published a full account. In the following summary, therefore, we have had to do our best with the information at hand.¹

THE NATURAL ENVIRONMENT

The Ryukyu islands form a curving chain extending 775 miles southwest from southern Japan to within sight of Formosa off the China coast. Consequently cultural influences and political pressures from China and Japan have bulked large in the Ryukyus' destiny. The Ryukyuan chain consists of 11 island groups and numerous scattered islets totaling a land area smaller than Delaware, larger than Rhode Island, but housing almost as many people as the two States together. Geologically the islands are the tops of three submerged mountain chains closely ranged together as if they were the strands of a necklace.

Ryukyu waters are warmed by the Japanese current, intensifying the heat of the southern monsoonal winds in the summer and ameliorating the cold of the northern monsoons in the winter. In this way seasonal climatic variation is less in the south than in the northern part of the chain. Rainfall is sufficiently heavy to stimulate lush natural vegetation on most of the islands, but the scarcity of natural reservoirs and the great depth of the ground-water table render the water supply a major problem on most of the islands. In addition, typhoons are frequent between May and October. Ryukyu homes and other buildings are built with the destructive forces of these storms in mind, but great property damage still results. Since typhoons usually strike in the growing season, crops are often destroyed.

The islands themselves have such varied terrains that they defy description as a group. Except for some of the low-lying islets, few have much flat land. Some have narrow coastal plains of clayey loam or sandy soil, overlying limestone deposits. These soils are rather fertile, but low-lying strips near the shore are frequently ruined for agriculture by tidal waves. Most shore lines show signs of submergence and the larger islands have bays suitable for anchorage. Where the coral reefs have not provided protection along the slowly sinking coasts, the sea has attacked the shore and cut cliffs and headlands.

¹ The best source material is in the Navy Department's Civil Affairs Handbook—Ryukyu (Loochoo) Islands. It was compiled before the invasion by a Navy Research Group at Yale University headed by Prof. George P. Murdock. Yale's Cross-Cultural Survey was the major source of information, but data provided by various Federal intelligence agencies were also used. We have leaned very heavily upon the Civil Affairs Handbook and the Cross-Cultural Survey, and are especially indebted to Professor Murdock for the large part he played in both of them.

We wish to thank Professor Murdock for his cogent criticisms of the manuscript, and Dr. Gordon R. Willey for helpful suggestions on organization. We are grateful to the U. S. Navy, J. Allen Chase, Dr. Leon Lewis, and Dr. A. C. P. Bakos for the use of their photographs.

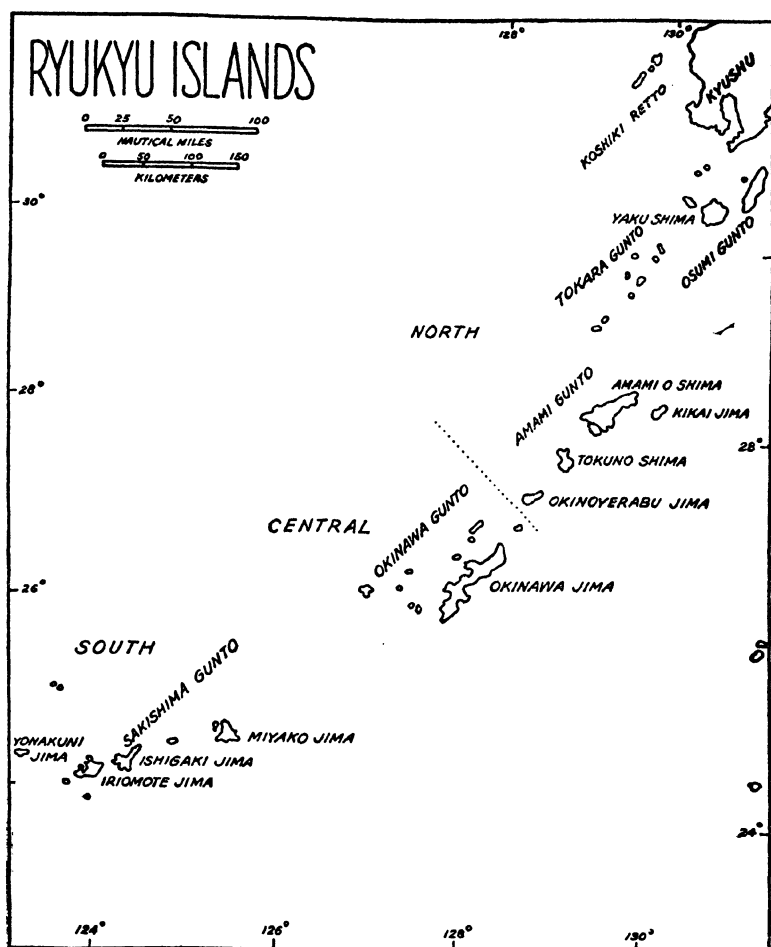


FIGURE 1.—Map of the Ryukyu Islands (adapted from the Navy Department's Civil Affairs Handbook, p. v).

Inland from the coast on most islands, the sloping or gently rolling terrain merges into rugged hills beyond. The plateaus and gently rolling lands are usually covered with well-drained, moderately fertile soils of clay and sand. The best lands are the alluvial soils in the shallow valleys. On the slopes of the rugged hills the covering of sandy loam has been washed thin, except where it accumulated in pockets. At best it is of mediocre fertility. Usually the smaller islands are less fertile than the larger, provide a less certain water supply, and consequently are less habitable. As in all but the most advanced civilizations, the environment has strongly molded and lim-

ited the way of life. In the Ryukyus, long considered culturally backward, we shall see how true this is. But first we must give background to the cultural picture.

THE PREHISTORY AND HISTORY

The Ainu.—The earliest inhabitants of the Ryukyu islands were probably a preagricultural food-gathering group closely related to the Ainu of northern Japan, but there is no positive evidence for this. Allegedly Ainu archeological remains have been reported² but the identifications need checking. It is possible that cultural traits harking back to the Ainu³ have existed in Ryukyu society within the past 100 years, but the matter has not been fully explored. Physical traits of almost certain Ainu origin, however, are said to have been present in many Ryukyans living in the latter part of the nineteenth century.⁴ This is the strongest suggestion of an Ainu occupation. If the Ainu were the first people in the Ryukyus, they were there in early times—the first or even the second millennium B. C.

The early Japanese.—Sometime before the third century B. C. a new people entered Japan from Korea, and spread slowly over the Japanese islands pushing back the Ainu there. These invaders were the early Japanese who bore a maritime culture of manifest South Asiatic character, and were closely related racially to the Southern Mongoloids. Some of these early Japanese settled in the Ryukyus, where they probably outnumbered the Ainu. The Ryukyu language, a sister tongue to Japanese, is attributable to these newcomers, and it is likely that they brought agriculture to the islands.

The early history of Chinese and Japanese contact.—Chinese annals of the third century B. C. contain the first historic mention of the Ryukyu Islands. But it was not until the early seventh century A. D. that the Chinese sent an information-collecting embassy there. Twelve years later Japanese records indicated that a delegation from the North Ryukyus paid their respects to the empress in Tokyo. During this early historic period Ryukyu relations with Japan were even more tenuous than with China, and were almost wholly carried on by upper-class people in the port towns of the island chain.

In the eleventh and twelfth centuries Japanese legendary history mentions small movements of people from Kyushu to the Ryukyus. Some of these emigrés were displaced nobility. The most famous was the archer Tametomo, who is said to have sired King Shunten—the ruler of Okinawa from 1187 to 1237. When Shunten ascended the throne, the Kyushu prince of Satsuma was given theoretical jurisdiction over the Ryukyus. This is part of the modern Japanese claim to the islands.

² See Newman and Eng, 1947, pp. 114–116.

³ See Murdock, 1934, pp. 163–191, for a description of how the recent Ainu lived.

⁴ Newman and Eng, 1947, pp. 121–123.

The period of greatest Chinese influence (1372-1609).—In the late thirteenth century China attempted to dominate the Ryukyus politically, and by 1372 had the Okinawa king paying tribute. With this entering wedge, Chinese-Ryukyu trade increased. This started a flow of more advanced customs and ideas into the islands, producing modifications in political structure, law and medical practice, the arts and literature, and funerary procedures. These modifications were largely felt by the upper classes, while the Ryukyu commoners continued their work-a-day life with little change. The net effect, however, was cultural advancement for the Ryukyus. In 1579 a Chinese emperor called the islands "The Land of Propriety." This title is deserved even to this day.

In the fifteenth century Japan forced the Ryukyuans to pay tribute to them as well. Perceptive islanders at that time could probably see that they were caught between their more powerful neighbors.

The sweetpotato, destined to become the staple food of the Ryukyus, was introduced from China in 1605. In 1623 sugarcane was brought in. Neither became vital to the Ryukyu economy for over two centuries.

The period of the Japanese protectorate (1609-1871).—Angered by the Ryukyuans' refusal to help in the Korean war, Japan conquered the North and Central Ryukyus in 1609. The North Ryukyus were ceded to her, and these islands were Japanese-governed from then on. The other islands retained more independence, at least in domestic issues, but larger questions of policy were settled by agents from Japan. Nevertheless the Chinese-style civil state was permitted to exist there for 260 more years.

Since China's ports were closed to Japanese ships from 1552 to 1643, and in 1636 Japanese merchants were forbidden to leave their country, the Ryukyu Islands became extremely useful as a means of indirect trade between the two countries. Naha, the main port of Okinawa, was used as a way-station in commercial transactions of high profit to China and Japan. The Ryukyus gained little capital benefit, and their position in this commerce can be likened to the trained fishing cormorants in the Orient that are kept on a string and forced to relinquish most of their catch.

The period of Japanese rule (1871-1945).—In the nineteenth century the Western powers showed enough interest in the Ryukyus to make the Japanese apprehensive. So in 1871, just 18 years after Admiral Perry broke the Japanese policy of seclusion, the Ryukyus were formally annexed by Japan over China's protests. Within a few years all the island chain was organized along Japanese lines. The colonial policy fostered complete assimilation of the Ryukyus into the political, economic, and cultural structure of the expanding Empire. In the 68 years before World War II this assimilation was

most complete in the North Ryukyus which Japan had dominated since the early seventeenth century. It was least complete in the undeveloped South Ryukyus, where much of the old culture still exists today.

Yet complete assimilation of the Ryukyu people was impossible since, despite official protestations of brotherhood, the islanders were looked down upon as uncouth rustics by the Japanese. The Ryukyuans had their own pride and according to Murdock (personal communication) considered themselves a subnationality of the Japanese. Thus they were Japanese in about the same way the Scots are British.

Cultural changes under the Japanese.—Officially imposed changes in Ryukyu culture were effected during the 74 years of full Japanese rule. These changes were cataclysmic to the upper-class natives, but were much more lightly felt by the commoners. And the smaller, less accessible islands were affected the least.

The Japanese commenced their assault on Ryukyu culture by lopping off the top of the native social hierarchy. By the 1920's the rigid and numerous class distinctions had disappeared. Almost everyone was a commoner, except for the Japanese officials, who were strictly top-dog. With the social reform, there was a reapportioning of arable land. Under the Ryukyu monarchy, land had been granted in fief to the upper classes, and the rest was divided communally among the peasants. But beginning in 1899 the land was allotted in small plots to independent farmers. Contrary to Japanese expectations, this did not increase the over-all yield, but it distributed the food supply more evenly among the people.

The Japanese inheritance laws were properly designed to keep the land within the family, but younger children did not receive a share. Since the small plots could only support an expanding family with difficulty, landless young men and women were often forced to seek a livelihood elsewhere. This tended to weaken the family structure. Although Japanese administrators were aware of this danger, they merely resorted to palliative measures.

The changes in planting of crops stimulated the food economy. In the final centuries of the Ryukyu monarchy, heavy subsidies were paid to wet-rice growers, and the number of flooded fields greatly increased. At the same time sugarcane growing was restricted. Since Ryukyu rice lacked hardiness and abundant yield, required scarce water, and took a lot of work, this was an impractical plan. Under the Japanese, *sweetpotato and sugarcane raising were encouraged, and were, respectively, the primary food and cash crops of the islands.*

Ryukyu food habits in the 1930's showed a strong shift to rice, but only half the required amount could be produced locally. Consequently, to reduce the necessary imports, Japanese agronomists introduced Formosa No. 65 rice, which was hardier and had several

times the yield of local varieties. As a result, in the few years before World War II, Ryukyu farmers were shifting back to wet rice wherever the land permitted.

Direct economic ties with Japan also stimulated local industries, especially sugar and silk production. This brought money and goods to the Ryukyus, but having part of the economy geared to world markets rendered the islands more susceptible to depressions. This is especially true when a country exports only two major products. So the drop in sugar prices after World War I caused widespread suffering in the Ryukyus, and large numbers left for lands of better opportunity.

Although industrial development never proceeded far in the Ryukyus, there was enough to threaten the old system of household crafts. This forced a shift in certain manufactures from the household to the factory, and required some workers to leave their homes and villages in pursuit of work. The Japanese-style mutual benefit associations, which appeared to be eagerly seized by Ryukyu craftsmen, did not compensate for the threat to the household.

A corollary change was the decline of native arts and crafts which the local market could not support and Japanese consumers did not care for. As an example, Ryukyu lacquerware of considerable artistic excellence used to be made, but the traditional designs lost out to Japanese styles. The native theater, dances, and music, formerly sponsored by the upper classes, disintegrated with their disappearance. The folk art of the peasants in the rural and more isolated areas is all that remains.

The effects of the assault on the old-time native religion are hard to gage, although no foreign creed ever had a large popular following in the Ryukyus. With the social and land reforms of this century, however, the native priestesses or "noros" lost their hereditary lands. Lacking their former wealth, these priestesses lost some influence, but were said to be still powerful in out-of-the-way places. With the rise of Japanese nationalism, official efforts were made to impose state Shintoism on the Ryukyus. This met with greater success in the North Ryukus than elsewhere.

Under Japanese rule, the population of the Ryukyus increased tremendously. From about 600,000 in 1890, it reached a peak of almost 880,000 in 1935. The natural increase was actually greater than this since about 200,000 Ryukyuans left the islands between 1920 and 1940 in search of better opportunities. Since immigration to the Ryukyus has been negligible within historic times, this rise in population meant an increased live birth rate, a lowered death rate, or both. Whatever the exact reasons for this gain, it was surely the most compelling reason for the great exodus of people to other lands. Out-movement became essential to the economic balance of the overcrowded islands.

It got rid of extra mouths to feed, and remittances sent home by prospering relatives abroad helped offset the unfavorable balance of trade recently characteristic of Ryukyu economy.

THE CULTURE

THE FOOD ECONOMY

The earliest inhabitants of the Ryukyus were probably scattered bands of hunters and fishermen, totaling only a very few thousand. Later, the introduction of agriculture, perhaps by the early Japanese, set the stage for a dense population. The intensive exploitation of arable land is as basic as the heavy Chinese and Japanese influences in the establishment of the complex feudalistic pattern of Ryukyu culture. Other factors which greatly influenced the local food economy were the seventeenth-century introduction of the sweetpotato, and the twentieth-century contributions by the Japanese toward more scientific farming.

The physical nature of the islands themselves has largely determined the limits of Ryukyu food production. In the Central and South Ryukyus, about one-quarter of the total land area was cultivated in 1939, with a smaller proportion under cultivation in the North Ryukyus. The total cultivated area perhaps could be increased 50 percent by farming potentially arable but untouched land, especially in the relatively undeveloped southern islands.

Almost three-quarters of the Ryukyu households engage in intensive subsistence farming, with many of them growing sugarcane as a cash crop. The prime food crop was the hardy sweetpotato, although just before World War II rice was becoming more of a dietary mainstay (see p. 384). In the late 1930's almost half of the cultivated land was devoted to raising sweetpotatoes. The small family plots of land, usually on the less fertile plateaus and gentle hill slopes, often produced two crops a year. As with all Ryukyu farming, cultivation was almost entirely done by hoe, although single horse or ox plows were occasionally used. Since sweetpotatoes are likely to rot in storage, it was customary to grate and then dry the surplus for future consumption. Lacking the knowledge of how to preserve part of the crop against a "rainy day," the sweetpotato never would have become a year-round staple food.

Rice was second in importance as a food crop, and was mostly grown in irrigated paddies in the shallow valleys and alluvial plains. Irrigated fields total about 10 percent of all the cultivated land in the Central and South Ryukyus, with a higher figure for the North Ryukyus where more rice was grown. In the North, there was one crop a year; in the Central and South, two were raised. Although about 40 percent of the farms in the two-crop area had rice paddies,

they were usually small and averaged half an acre. With the demand twice the supply in the late 1930's, rice imports from Japan were high. During World War II, these imports were reduced.

Ryukyu methods of wet-rice culture were virtually the same as those of other Far Eastern countries. Irrigation involved no reservoirs or canals, but only called for diverting stream water into narrow channels to the terraced paddies. The water then filtered from higher to lower paddy. Manure, night soil, cover crops, compost, and some commercial fertilizers were used on rice and other fields. The use of all available natural fertilizers, so shocking to people of the Western world, was characteristic of the extreme economy of Ryukyu life. The hoeing or plowing, harrowing and leveling, transplanting of seedlings, weeding, and harvesting were almost wholly done by hand.

Other grains were grown, but did not bulk as large as food crops. These were wheat, millet, and barley. Although broadcast sowing was known, it was more usual to plant seed in rows of holes with a simple digging stick. Some root crops other than the sweetpotato were cultivated in minor quantities. Truck gardening and raising of hay and other forage crops were little practiced. On steep slopes and otherwise infertile lands, cycads (*Cycas revoluta*) were grown from seedlings. The pith of these trees was washed, dried, and made into sago flour, which was used by the very poor, or in times of famine. Under the Ryukyu monarchy, cycad cultivation was sufficiently important to have an official in charge of it.

Sugarcane was grown as a cash crop on about one-quarter of the cultivated land in the Ryukyus. It was preferably planted in the clay soils of the coastal plains, but was especially susceptible to typhoon damage there. Most plots were small, rarely over an acre in size. Although there were a few large sugar "centrals" most of the cane was crushed in small, literally one-horse mills of original Chinese design. The cane juice was then boiled, put in clay trays for drying, and exported in unrefined state.

Animal husbandry and fishing were overshadowed by agriculture. Most farm households had a hog or two and several goats. Fewer owned horses and cattle. Stock farms were almost nonexistent in the Ryukyus, so most of the slaughterhouse meat came from the small farms. Home-grown pork was more frequently eaten than other meat. It was a large enough item in the diet to elicit the contemptuous nickname "Pork-eater" from the Japanese. At the onset of the war, meat consumption was cut until it reached the average table only about four times a year.

Most Ryukyu fishermen operated from small offshore craft. (See pl. 3, center.) Their commercial catch was small compared to the few deep-sea fishermen who seined, drag-netted, and hooked bonito from large boats. More commercial fishing was done in the North Ryukyus

than elsewhere. Lack of a well-equipped fishing fleet restricted the over-all catch, although Ryukyans were famous all over the Pacific as fishermen. Their commercial fishing techniques were unexcelled throughout the world, according to professional fishing men (Murdock, personal communication).

OTHER WORK

While three-quarters of the gainfully employed produced food, the remainder made a living in crafts, services, and commerce. The proportions employed in these categories were, respectively, 12, 7, and 5 percent in 1930⁵ for the Central and South Ryukyus. Most of those engaged in crafts made goods of Japanese design for export. A smaller number produced hand-made utilitarian items for the local markets, or were in the building trade. The rest did relatively unskilled manual work in such industries as mining, quarrying, and lumbering.

In the Central and South Ryukyus, the major service occupations were, in descending order, banking and insurance; hotel, restaurant, and entertainment; transportation; domestic service; education; and government service. The numbers in religious, legal, medical, literary, and artistic fields were notably small, but need not indicate intellectual impoverishment under the Japanese. On the contrary, the literacy rate was high, and even the peasant homes appear to contain more and better books than the average American home (Murdock, personal communication).

In the field of commerce, most of the people were small local merchants, although a few had trade connections with Japan and Formosa. Most rural settlements had general markets where vendors sold food, ceramics, cloth, and tools, but these were on a decline in the 1930's and 1940's. Specialized markets for such commodities as livestock were located in the larger towns. Retail shops in the cities increased in number, owing perhaps to the influx of Japanese capital there. In addition, a few branch stores were established by Japanese firms.

FOOD HABITS AND DIET

With the exception of some food imports and local barter, the Ryukyuan people ate what they raised and caught. Sweetpotatoes, therefore, were the national food, with rice an important secondary item. Other vegetables, such as soy beans, cabbages, carrots, green onions, eggplants, squash, cucumbers, taro, and small tomatoes, were eaten only in minor quantities since many households did not raise

⁵ It is improbable that the 1940's brought much change in these figures. As Japan girded itself for war, some Ryukyuan weavers were forced into other occupations, and others were conscripted for work in the Empire's war plants, or for military service abroad. Of those remaining in the Ryukyus, the proportions engaged in food production, crafts, services, and commerce probably remained the same.

truck gardens. Some flour from wheat, millet, or barley was used, but usually just for occasional fancy baking. Noodles and imported vermicelli were also used. Fresh fruits were rarely eaten. Fish and especially meat were "prestige" foods, which is another way of saying that not everyone could afford them. They appeared on the family table as often as availability and buying power permitted. Horse mackerel, shark, flyingfish, tuna, and bonito represented the largest coastal catches. Cuttlefish, octopus, shellfish, and seaweed were also taken. In times of famine, the coral reefs and rock pools were thoroughly searched for edibles. Most of the meat was pork, with goat flesh secondary in importance. When not eaten fresh, it was salted down for future use. Beef was also eaten, but was more likely to be exported on the hoof. Indeed, many farm households felt they could ill afford not to sell much of their livestock.

Food was most usually boiled or cooked in vegetable oil or pork fat. Steaming and baking in brick ovens were practiced in some households. Foods were seldom eaten fresh or raw. The most common seasoning was soy bean sauce, and in addition salt, vinegar, and tomato paste were used.

Compared to Western dietary standards,⁶ Ryukyuan diet appears to be bulky and to have a high carbohydrate content. It has been suggested that the unusually long, large colon of the Ryukyuans may be an adaptation to this bulky vegetarian fare.⁷ High-quality proteins and fats seem somewhat lacking in their diets. Further analysis might indicate a low intake of one or more of the B vitamins. But regardless of how the diet measures up to modern nutritional desiderata, the Ryukyuans did very well on it. On the basis of their hardiness, longevity, fertility, and small amount of metabolic disturbances and deficiency diseases, Steiner (1947, p. 241) feels the diet to be well suited to the people. This in turn would imply the basic adequacy of the food economy.

TECHNOLOGY AND ART

Architecture.—Public buildings built in modern times closely follow Japanese and occasionally Western architectural styles and are usually of cut and mortared stone or concrete construction. The old castles and shrines of yesteryear Ryukyu show considerable Chinese as well as Japanese influence. The larger ancient structures were strongly constructed of cut stone, and ones like Shuri castle were even hard to reduce by bombing and shellfire. Smaller edifices were made of stone or mortised frame and panel construction.

Home dwellings range from the temporary rural hut shown in plate 4, lower, to urban homes as elaborately made as the priest's house in

⁶ See Steiner, 1946, pp. 18–19; 1947, pp. 240–241.

⁷ Steiner, 1946, p. 5.

plate 4, upper. The simple rural houses were usually rectangular with thatched roofs and walls made of two layers of bamboo lattice with a straw filler in between. No windows were used, sometimes even a smoke hole was lacking, and the floors were often packed earth. Better rural homes had more rooms, paneled walls, raised board flooring, and even tiled roofs, but this was more the urban style. In these homes the family shrine occupied an important place in one of the rooms. It was a highly stained and polished waist-high cabinet with frames and sliding panel of elaborately cut lattice. Within were at least two steps housing family name plates and other objects. The rest of the house might be very plain, but the family shrine was as exquisitely made as the household could afford.

Rural dwellings were almost always surrounded by a live hedge, a stone wall, or both, if money permitted. As can be seen in plate 3, upper, the entrance to the compound was sometimes guarded by a short wall just within. In addition to the main dwelling, there was a stable, small storage house, and a pigsty directly under the latrine. A cistern or well usually completed the farmstead structures.

In the urban homes, sliding paneled walls, board flooring, and hipped tile roofs were used where they could be afforded. Usually these homes were surrounded by a high stone wall. Within the courtyard, small storage structures and pigsties were usually present.

The most unusual feature of Ryukyu architecture was the womb-shaped tomb of South Chinese inspiration. (See pl. 3, lower.) Most tombs were set into steep banks and hillsides unsuitable for farming, but were by far the most costly family edifices. The approach was through an outer courtyard walled by hewn rock. These walls joined the lateral abutments of the tomb. The tomb itself, carefully constructed of concrete or cut stone, was pear-shaped with a flat or low-domed roof. The entrance to the funerary vault was large enough to admit a coffin. Within the vault the remains of recently deceased family members lay in coffins, while the carefully cleaned bones of the long dead were deposited in elaborate pottery jars of native make.

The burial customs were part of the ancestor worship, an integral part of the old Ryukyu religion, embellished by Chinese customs. Currently the Japanese cremate their dead, and have disseminated this practice to the North Ryukyus. Cremation was rare, however, in the South and Central islands, although not every family could afford a burial tomb. Poor families were more likely to place their dead in caves or cemeteries.

A fine family tomb was a prized possession, and took great sacrifice to construct. Often a family might live in a hovel, but would labor lifetimes to possess a suitable resting place for its dead. A fine tomb was considered much more important than a fine home.

Transportation and communication.—The larger and more heavily

populated islands have narrow roads, mostly running along the coasts and connecting the larger towns. Few roads were cut through rugged terrain, so that the more isolated areas were served only by footpaths. Most of the smaller islands had only trails. The roads were usually made of limestone topped with coral sand, and were nationally, prefecturally, or locally maintained. Cut and fitted rock bridges were used to traverse streams on the major roads.

Owing to a heavier population and more favorable terrain, most of the roads were in the Central and South Ryukyus. The bulk of these were on Okinawa Jima. Even so, the total of 4,000 miles of roads over the entire Ryukyus in 1939 is small as compared with areas the same size in this country.

Major Ryukyuan cities had many broad and well-paved streets. In 1939 Naha and Shuri (combined population of over 80,000) had a street system totaling almost 1,300 miles.

Most of the vehicles were bicycles, rickshas, and horse-drawn carts. There were few automobiles and busses. In 1939 the Central and South Ryukyus had a total of 504 miles in bus routes.

Railroads were of little consequence in Ryukyu transportation and were only narrow-gauge spur lines between large towns, or were used in nationally-promoted mining and lumbering activities. Steam and gasoline engines were used, as well as horse cars.

Means of water transportation ranged from the single-log native dugout through motor launches to the small Japanese steamers which touched only the several main ports. Most of the interisland traffic was by motor sampans and larger sailing craft. The bulk of the ocean travel was by Ryukyuans in search of seasonal or permanent employment. Few Japanese or other foreigners visited the islands.

Communication between the larger islands and Japan was possible by radio, submarine cable, airmail, and regular mail. Small post offices were located in almost every township, in addition to those in the larger towns. Telegraph and telephone lines connected the post offices on the same island. In addition to a small circulation of Japanese newspapers, a handful of 2- to 8-page local papers were printed. The circulations were not known, although plenty of newspapers were found in abandoned rural homes during the invasion. Both the Japanese and local press were rigidly controlled.

Utility crafts.—The textile industries employed more people than all the other crafts combined, and rivaled sugar production in capital return. Most of the work was done by hand, producing goods of excellent quality mainly for Japanese luxury trade. The first ranking textile industry was silk, wherein an expert weaver would take 2 or 3 months to produce 10 yards of high-grade material of 14-inch width. Most silk was made in the North Ryukyus. The next most important

was the Panama-hat industry, confined largely to the Central Ryukyus. Linen cloth made from the fibers of the textile banana constituted the third industry. Its manufacture was concentrated in the South Ryukyus. Other textile products were rush matting, cotton cloth, and straw articles. A large part of the weaving in all textile industries was done by women on hand looms in small shops or at home. Natural dyes, especially indigo and the juice of the Japanese hawthorne, were still used, although larger factories had begun aniline dyeing. Both batik and vat dyeing were practiced.

Other manufactures in the Ryukyus were conducted on a very small scale. Carpenters and stone masons still performed high-quality work in the cities, despite their rather primitive tools. Food processing and canning accounted for a few more workers, and dealt largely in dried bonito, and canned meats and vegetables. Other small industries only worthy of mention were machine and metal work, wood and bamboo working, paper manufacture and printing, ceramics and tile, and mining and quarrying.

The arts.—The leveling of the native class system by the Japanese had the effect of abolishing the national art of the Ryukyus. Lacking upper-class patrons for luxury goods of traditional design, craftsmen turned to Japanese markets for an outlet. This meant that the patterns and decorative styles were dictated by Japanese fashions. Traditional designs lost out, except in crafts such as architecture and woodworking which catered to the small local market. Ryukyu ceramics and lacquerware used to be of high artistic excellence, owing largely to Chinese influence. Recently, however, only building tile and pipe and cheap utilitarian and ornate funerary ware were produced for local consumption. The exports followed Japanese designs, usually the more gaudy. The textile industries alone retained much of the old-time technical excellence, but had to use Japanese styles.

As with the artistic crafts, the Ryukyu theater, music, and dance had disintegrated from lack of upper-class patrons. In the cities traditional forms of entertainment were largely replaced by Japanese-style performances, especially by geisha. The rural areas still retained their folk music and dances, which figured largely at the annual festivals.

THE SOCIO-POLITICAL PATTERN

Settlement pattern: The family.—The biological family, consisting of parents and their children, was the basic unit of Ryukyu society. Economic and religious pressures made family ties particularly strong. Great family solidarity, almost to the exclusion of other loyalties, was encountered by Americans during the invasion. It was almost impossible to secure volunteer blood donors or nurses

among the Okinawan civilians unless the welfare of an immediate family member was involved.⁸

Within the family, the father was the household head, but did not achieve the authoritarian status found in Japan. The status of women was considerably higher than in Japan or any other country in East Asia (Murdock, personal communication). Although all contributed to the household's support, the members of a Ryukyu family controlled their own finances, and only lent money to other members at interest. The differential behavior toward younger and older family members, and toward those of the opposite sex was almost as formalized as in Japan. These distinctions are reflected in their kinship terms, which otherwise are comparable to our own.

Although some family households were large, the average one consisted of four to five people. Many households lost at least one member as a result of the heavy 1920-40 emigration, so the size of the average family would have been somewhat larger. Reliable information on the number of children per family is not available. On Okinawa Jima, Steiner (1947, p. 240) states that it averaged five or six, but questionnaire returns in 1945 from 1,000 Okinawans gave a mean of 3.7 for families having children.

In Ryukyu society a group of families related in the male line formed a clan. Since married sons often settled near their parents' households, clan members tended to cluster in communities. In former times, these patrilocal clans had considerable power, but more recently were overshadowed by the village group and the mutual benefit associations. In out-of-the-way places, the clan still retained its strength.

Landholding and land tenure.—In the North Ryukyus the Japanese pattern of extensive tenancy prevailed, but to the south reallocation of small plots to individual farmers early in this century made for wide diffusion of private ownership. In 1935 the tenancy rate for the Central and South Ryukyus was only 10.5 percent. One thousand questionnaire returns from Okinawans in 1945 indicated that 24 percent were tenant farmers. Small as this sample is, it suggests that tenancy increased from 1939 to 1945, possibly as a result of bankruptcy of small independent farmers or the breaking up of their families by conscription and emigration.

Most of the privately owned and operated farms in the Ryukyus were very small. In 1939 they averaged 2.1 acres in the North, 1.6 acres in the Central and South Ryukyus. Rights of possession and transference of private land were regulated by the Japanese civil code. The chief aim of the inheritance laws was to keep the land within the family as far as possible. This tended to bolster the household by protecting its means of material support. Nevertheless, creditors had the right to seize private land in lieu of a debt.

⁸ Moloney, 1945, p. 395.

The physical nature of the communities and their functions.—Since the arable land was largely divided into small plots, farm houses were not far apart. This can be seen in plate 1, upper. More often, however, these houses were clustered in small villages (see pl. 1, lower) ranging in size from only a few families to over 1,000 people. These villages resulted from a natural growth, perhaps starting with only a few related households, and later adding other kin groups and single families. These kin groups of a number of households related in the male line often formed subsettlements in the rural villages, but were generally of less functioning importance than the village group.

The locations of villages were determined by several factors. The desire to conserve arable land for crops favored using the less fertile areas for villages. On the other hand, the less readily cultivated hilltops and ridges were exposed to the full force of typhoons, and hence were often avoided for village sites. For this reason, some Okinawans were dismayed at the American tendency to erect hospitals and other installations on the higher and more exposed land. More usually, therefore, Ryukyu villages were located along the flats, in valleys, and on the lee slopes of the hills.

Most villages had a central area for markets and other communal affairs. Festivals, geared to the economic and religious annual cycles, were also held there. Also administrative matters, in part passed on to the village headman from the township officials, were discussed and put into practice in the central area. In any village, this area embodied the core of the local society. This was where the people got the word.

Although the Ryukyus were largely rural, nine settlements became large enough to classify as towns or cities. These ranged in size from about 7,000 to 66,000, and totaled almost one-quarter of the total 1940 population of the islands. Several of these, notably Naha on Okinawa Jima and Naze on Amami O Shima, were port towns or cities. The rest were merely overgrown villages, set apart only by their size and the presence of modern administrative and commercial buildings. The towns and cities served largely as mercantile centers, and also in most cases were the focal points for voting, agricultural, police, and postal organizations.

Class structure.—Although early in this century the Japanese leveled the native hierarchy of social classes, enough time has elapsed since then for a social system patterned after the Japanese to begin to take hold. In this system holders of administrative and educational posts enjoyed the highest status. Next, and pressing these officials closely, were the larger landowners. As Murdock (personal communication) says, a man with five or more acres of farm land was considered rich and was much respected. Village heads, assemblymen, and teachers were usually drawn from upper middle class landed households. Below them were the rank and file of artisans, fishermen,

tenant farmers, and small shop, restaurant, and hotel keepers. In addition, when sugar prices were high, a small group of nouveau riche sugar producers sprang up to occupy top positions in the upper middle class until the market turned downward.

Associations.—Occasionally cutting across the growing class lines, but mostly operating within the class level were the characteristically Japanese associations, designed to align those people interested in accomplishing specific things. Some of these were government sponsored and controlled, especially the patriotic, reservist, and youth organizations. Others were more spontaneous and developed from specific economic needs. Of these, farmers' buying and selling cooperatives were the most numerous. As Japan tightened its economic belt for war, the government took over many of these spontaneous associations to achieve higher production. Other minor associations were concerned with civic, cultural, and wholly social affairs. All associations were checked by the police, but sometimes this was only perfunctory.

Formal government.—In the Japanese administration, the prefecture stands immediately below the Imperial Government and usually deals with the local units directly. The Northern Ryukyus were administered as part of Kagoshima prefecture; the Central and South Ryukyus, comprising the whole of Okinawa prefecture, were administered as a unit. Prefectural governors were appointed by the Prime Minister, and operated with a secretariat and four departments—General Affairs, Education, Economic Affairs, and Police. An elective assembly served the governor in a largely advisory capacity and had virtually no power. In addition representatives of the various Imperial Ministries were assigned their specific duties in the Ryukyus. Except for the governor, his advisors, and an occasional high official, most of the administrative posts were held by Ryukyans.

Within the prefectural governments in the Ryukyus, branch offices were established on the more remote islands to facilitate their administration. Two such offices were present in the North, two more in the South Ryukyus. The Central islands were themselves the seat of the Okinawa prefectural government and needed no branch offices.

The seats of the local administrative units were the cities, towns, or in rural areas, townships. In all cases the mayor or headman and their staffs were elected by the local assembly, which in turn was chosen by popular vote of all male residents over 25 years old. These city, town, and township administrations could operate autonomously in purely local issues, subject of course to a veto from higher up. On policy matters, however, their courses of action were dictated to them. In rural areas the village heads were appointed by the township headman and served without salary, but had local prestige well worth the troubles of office.

RELIGION

The native animistic religion has survived in little-modified form in the Central and South Ryukyus. Owing to long-time Japanese domination, it was less strong in the Northern islands. Its strength, however, from Okinawa south is indicated by the absurdly small number of adherents to foreign religions in that area. For 1937 less than 4 percent of the people were Buddhists, less than 2 percent Shintoists, and only 0.2 percent Christians. This means that 94 percent of the people practiced their old-time religion, although a few may have had no religious feelings at all.

The essence of this folk religion was the endowment of natural phenomena with supernatural forces. Thus fire, mountain peaks, the sea, and groves of trees made up a pantheon of spirits, to which the people paid homage. Locally sacred areas were marked by fetishes. Temples came as a later, probably foreign-influenced, development.

The worship of these vague naturalistic spirits is an old and very widespread form of religion. Particularly striking in Ryukyu religion was the veneration of the hearth, which was sacred to the fire god. Also noteworthy was the cult of sacrosanct priestesses, or "noros," for whom celibacy was once a requirement of office. These "noros" were almost the sole religious practitioners of the native religion, although lesser female assistants took minor roles. The office of "noro" was largely confined to certain families and was passed on from generation to generation with the paraphernalia of sacred objects—a vesture, tablets inscribed with names of ancestral priestesses, a string of crystal beads with jewels or stones in between, and a fire-god fetish.

Almost every village had a "noro" who sometimes wielded great enough power to reverse the will of the people. A "noro" figured prominently in the village-square festivals and was consulted at other times for prayers and advice. Less benevolent practitioners were the fortune-tellers, or "yuta," who in addition to clairvoyance, would propitiate evil spirits and ghosts. The Japanese administrators felt the "yuta" abused their influence and in recent times outlawed their operations.

THE LIFE CYCLE

There is little information on childbirth practices in the Ryukyus immediately prior to the war. In 1939 the ratio of physicians was about 3.5 per 10,000 population, and the number of registered midwives not much higher. The 1945 questionnaire administered to 471 Okinawan mothers indicated that 58 percent of the women were attended by midwives for the last child, with the remainder almost wholly unattended professionally.

Formerly, both mother and child were kept close to the sacred family hearth for a week, while friends and relatives made loud music

day and night. This custom may still persist in out-of-the-way areas. Other ancient customs, such as placing a crab on the male baby's head to insure early crawling, may also be found in the recent culture.

Once the baby came into the Ryukyu world, we have the word of an American psychiatrist⁹ that it was well mothered. Of 241 Okinawan mothers questioned in 1945, the average age of weaning their last child was 3.8 years (Japanese).¹⁰ During that time a mother seldom left her child, but carried it on her back in a sling. No set feeding schedules were followed, but the baby was nursed when it desired. When it was weaned the baby was taken over by a substitute mother, usually the next elder sister. These "little mothers" carried their charges in slings or led them around, and continued the Ryukyu system of good mothering. In contrast to the Japanese who commence rigid bowel training well before a baby is 1 year old (Western), Ryukyu mothers made no such attempt until their offspring reached at least a year and a half. At that time the training was largely a matter of emulating the older children. A significant aspect of child training is pointed out by Moloney (1945, p. 394), who states that only once did he see a Ryukyu mother corporally punish her child.

When the child was over 3½ years old (Western) it was ready for school operated under the Japanese educational system. As Moloney (1945, p. 394) says, "One not familiar with psychological maturative processes would be inclined to believe that the Okinawan brand of mothering would produce a self-centered, a spoiled, an undisciplined child. On the contrary, they show themselves capable of harmonious social cooperation * * *. Calm, confident, and without fear, they obeyed their elders, but were not obsequious." He emphasizes that Japanese doctrine did not reach a Ryukyu child until, under the protective tutelage of the home, its basic personality structure was already well consolidated. During the next 6 years in the nominally compulsory lower elementary school, Japanese indoctrination only made a superficial impression on the children. Like their parents, they learned to pay "a superficial and expedient homage to Imperial Japan."

Differential treatment of boys and girls began at preschool age and was continued with more force in the schools. At early ages, both sexes were taught their ascribed status in society, so that they knew how to treat those people with whom they came in contact. These behavior patterns for girls required more humility and deference than for boys. In the early training of both sexes, however, respect for

⁹ Moloney, 1945, pp. 392.

¹⁰ In Japan and the Ryukyus a baby is considered 1 year old at birth, and picks up another year the following January 1. Thus a baby born December 31 is 2 years old the following day, but a baby born January 1 does not become 2 years old until the following January 1. On the average, Japanese ages are 1½ years ahead of Western ages.

elders was emphasized. The etiquette of ostentatious self-abasement, however, never reached the heights seen in modern Japan. "Face" was nevertheless important in Ryukyu society, and the mechanisms of face-saving were learned early in life.

Ordinarily a child attended school for 6 to 8 years. Emphasis there was placed in the following order upon Japanese-style "ethics," the Japanese language, use of the abacus for working arithmetical problems, and memorization of large numbers of Chinese characters. For the sake of "health" and also to promote national solidarity, group calisthenics were often coordinated by radio with similar activities all over Japan.

During the school years, boys and girls were taught to be useful at home, and shouldered household burdens as soon as they were able. Girls usually took care of younger brothers or sisters. Boys assisted older men in the family in the more specialized male tasks. Both boys and girls did their stint in the field, especially at harvest time, often dropping out of school to do so.

At the age of 13 (Japanese), both went through coming-of-age ceremonies. These involved the first wearing of adult clothes, symbolic of the end of childhood and the assumption of a grown-up role in society. In recent times these ceremonies were of a more perfunctory nature, particularly since schooling might not be completed until the next year, or even later if more advanced education was desired and could be afforded.

At about the turn of the century, 14 to 17 years was considered the proper time for marriage. Matches were almost always arranged by the parents. In the 1920's and 1930's, however, marriages began taking place later in life. By 1937 the average ages for first marriages were 27 for men and 24 for women. Obviously, as in Japan and the United States, most young Ryukyuans were not well enough fixed financially to marry in the 'teens. In addition, military conscription took many young men out of circulation for a while when they reached 20 years of age.

The betrothal in an arranged marriage involved visiting ceremonies, led by intermediaries. Details varied locally, and some of the marriage customs described in the literature may no longer be practiced. Both the "wife search" in the North, and "bride capture" in the South Ryukyus may now be things of the past. The marriage ceremony itself was held in the groom's home. It was sometimes customary for the groom's party to leave the bride for a belated and lengthy "bachelor dinner" but this luxury could not be afforded by the average young farmer.

Ryukyu marriages were easily broken by common consent with a minimum of family turmoil. The divorce rate in the Central and South Ryukyus was higher in the 1930's than in any other Japanese

prefect. The broken homes occasioned by easy divorce apparently did not cause appreciable maladjustment in the children. The reasons for this are obscure and would merit special study.

Almost all married couples and their children lived in a narrow work-a-day world which called for hard labor and great frugality. Americans were particularly impressed with Ryukyu woman's hard lot, not realizing her relatively high social status. It is true that the women worked in the fields, did the housekeeping, raised children, carried heavy burdens, marketed much of the produce, and performed many other routine tasks. But the men of the working class also worked hard. Theirs were more specialized tasks, such as building, carpentry, and irrigation, as well as a good part of agricultural work. Both sexes were extraordinarily well muscled and hardy. The small number of days a year when they were too sick to work would make a proud record in the United States.

This physically strenuous life, coupled with low emotional tensions and a simple and largely vegetarian diet, apparently made for late senility (Steiner, 1946, pp. 22-23). The number of elderly people compared favorably with that of Western countries noted for their medical science. Outstanding in the Ryukyus was the very small amount of heart disease, alimentary and kidney disorders, cancer, and other degenerative changes so common in the more civilized world.

Old people were able to remain active most of their lives. When they could no longer carry on, their families took care of them. Above all, special care was taken to give them a proper funeral and place the coffin in the family tomb. Years later the unmarried girls of the family would carefully clean the bones in sweetpotato brandy, and reverently place them in a funerary urn. Within the vault these urns were arranged on an altar according to the status and kinship of the persons whose bones they contained. The bones of the husband and wife were often placed together in a single urn, so they could grow old together. It is reported¹¹ that the tombs were deliberately fashioned in the shape of a womb, and that the Ryukyuans considered death merely a return to the place from whence they came.

THE RYUKYU CULTURE PATTERN AND THE RYUKYUAN'S WORLD VIEW

In the past 1,000 years or more, the influences of Chinese and Japanese civilizations were largely absorbed by the upper class of Ryukyuans. Some of these foreign customs filtered through to the commoners, who in the main went on eking out their simple rural existence much on the same cultural level as the medieval Japanese peasant. After Japan annexed the Ryukyus, she lopped off the upper classes there, placing almost everyone in commoner's status.

¹¹ Moloney, 1945, p. 396; Steiner, 1947, p. 311. We consider these reports of questionable validity, but cannot disprove them.

What remained of the indigenous Ryukyu culture was only the peasant part of it. The esoteric character of the upper-class native life was lost, to be replaced by Japanese customs. The peasant culture has been outwardly changed by new food plants, limited participation in world trade, Chinese manners, and Japanese regulations. Yet inwardly it reflects an old pattern, the core of which probably goes back to an early agricultural level.

This core is the food economy. It has never been easy for peasants to make a living in Ryukyus, and to do so most effectively has required hard physical work, cooperative effort, and frugality. This hard work was performed cooperatively by family members, who farmed small plots of land in tenancy or actual ownership. This placed tremendous strength in the in-group solidarity of the family, which was reinforced by a religion emphasizing the sacredness of the household hearth and the veneration of ancestors. Within the family relationships were regulated by differential behavior patterns for each member. Only enough freedom of action was permitted to absorb domestic tensions and alleviate otherwise intolerable personality clashes. Where husband and wife were so unsuited as to threaten family solidarity, divorces occurred. These were accomplished with a minimum of controversy, the wife returned to her people, and the rest of the family carried on until a more suitable wife and mother was brought in. Children were usually extremely well mothered, and were serenely brought up to take their ascribed adult status in the family and the immediate society. Family "face" was as important as individual "face." Both were preserved at almost any cost.

Village ties were much less important than the solidarity of the family, but in modern times transcended the bonds of the patrilineal clan. Ties to the village were motivated largely by economic matters. Cooperative building, construction of roads, and improvement and repair of irrigation systems were some of the village enterprises. Group participation in religious ceremonials and social events, marriage bonds between village families, and the village market helped cement village solidarity. In times of great stress, although a Ryukyuan would do a great deal for his family, he would probably make no great sacrifices for a fellow villager. In all probability, he would reject the thought of aiding an outsider. The loyalties were first to the family and then to the village. In his world view, the Ryukyuan probably did not see far beyond either one.

To make a living in the Ryukyus, everything had to be used. How else could four or five people derive their support from an acre and a half of hand-tilled soil? Projecting this frugality into the psychological realm, Moloney (1945, pp. 394-395) suggests that it makes for the realistic attitude that worthless things, people included, are to be rejected. As he says, "Apparently * * * social consciousness

does not extend to that which is no longer valuable" (*ibid.*, p. 395). As an Okinawan might have expressed it in a United States Navy hospital (see p. 392), "Why should I give blood to a countryman whom I don't know, and who will probably die anyway?" In terms of this realism, and the in-group solidarity which blots out other ties, there would be no answer to him.

The possession of a sometimes ruthless realism did not render the Ryukyans "almost devoid of religious sentiments," as Leavenworth (1905, p. 38) would have it. To be sure, few natives were converted to Buddhism or Christianity, but in their own way they made strong identifications with the supernatural. It is important to note that these identifications were on a practical level. The old-time religion held that all of nature was alive and endowed with spirits. Because the people realized their helpless dependence upon nature, fire, mountain peaks, groves, rivers, and the sea were construed as vague but powerful friendly or unfriendly forces. The prayers and ceremonies were to please the friendly forces, and, insofar as their feeble powers permitted, placate the unfriendly ones. There are no indications that the belief in inimical spirit forces made for a fear-ridden society. Possibly the popular attitude was rather one of resignation, which might be expressed as "We will do what we can, and observe all the proprieties. Then come what may." In their practice of ancestor worship, the elaborate funerary procedures were also carried out to the letter. Apparently there was deep satisfaction to be derived from properly honoring the dead. A fine tomb for this purpose was a prime goal in Ryukyu culture.

THE WAR AND THE FUTURE

The assigned task of the Ryukyus during World War II was to provide military conscripts and war workers to the Empire and to tighten the belts at home. As the Japanese military position became desperate, more and more Ryukyans were fed into the war machine. And beginning with the heavy United States air strike on October 10, 1944, bombed-out natives fled to southern Japan. So by the time of the invasion, the civilian population of the Ryukyus was as low as it was about 1900.

Okinawa and adjacent islets felt the smashing effect of a shooting invasion, while only the military areas of other islands were bombed and shelled by American and British forces. On Okinawa itself, some 30,000 able-bodied native men were pressed into the Japanese defense force of some 120,000. In many cases their families went with them and were caught in the bitter fighting. Most of the civilians, however, hid out in the hills and in caves under overcrowded and difficult conditions until they were brought out by the Americans. In addition to the injuries of war, the lack of food, warm clothing,

sanitation, and medical care took heavy toll. One out of eight died as a result of the invasion and the losses of able-bodied men and of infants were proportionally much higher.

The Okinawan civilians were crowded into Military Government camps back of the lines (see pl. 2). Until the salvaged food in the area of these camps was exhausted, most interned Okinawans were fed enough to sustain life. None were fat, and emaciation, while not the average condition, was common enough. By early summer, their losses in body weight were not as great as their hardships would lead one to suppose.

In midsummer of 1945 most of the 300,000 civilians were transported to new Military Government camps in the more barren northern part of Okinawa. There they suffered great privations despite American efforts to take care of them properly. Housing was most primitive (see pl. 4, lower), sanitary facilities and water supply were meager, and food was considered abundant if one day's supply was on hand. In the early fall a nutritional survey (Culbert and Lewis, 1945) reported that 10 percent were on the borderline of starvation, while 43 percent showed signs of early malnutrition. Average body weights taken by ages were down 10 percent as compared to the early summer figures.

Commencing in the late fall of 1945, the internees were gradually released and permitted to settle in their home areas. The homes of 90 percent of them had been destroyed during the invasion, and many of their fields had been ruined or were reserved for military installations. Part of the tremendous task of resettling involved aiding them in building new homes, reclaiming and releasing arable land, and feeding and clothing them until they could become self-sufficient.

The problems of Military Government were somewhat less difficult on the less war-torn islands. In 1947, however, the total Ryukyu acreage planned for cultivation was only about 60 percent of the pre-war figure. This reflects the over-all dislocation of Ryukyu economy, and explains why even in the first half of 1947, one-third of the food consumed in even the most basic rations had to be imported from the United States. These imports are being gradually reduced, pending the time when the Ryukyus will be self-sufficient in food supply.

While this reconstruction of Ryukyu economy was going on, over 200,000 Ryukyuan from all over the Pacific were brought back to their homeland. This repatriation began in early 1946 and was virtually completed that year. This brought the June 29, 1947, population to 44,000 more than the early 1944 figure, so that the Ryukyus are now as overcrowded as they ever were. The current hope for rendering the Ryukyus self-sustained in food supply is the work of mechanized land-reclamation teams, cooperating with the farmer's associations. If all the arable land is utilized (see p. 386), it may be sufficient to support the present population. Rehabilitation of the fishing

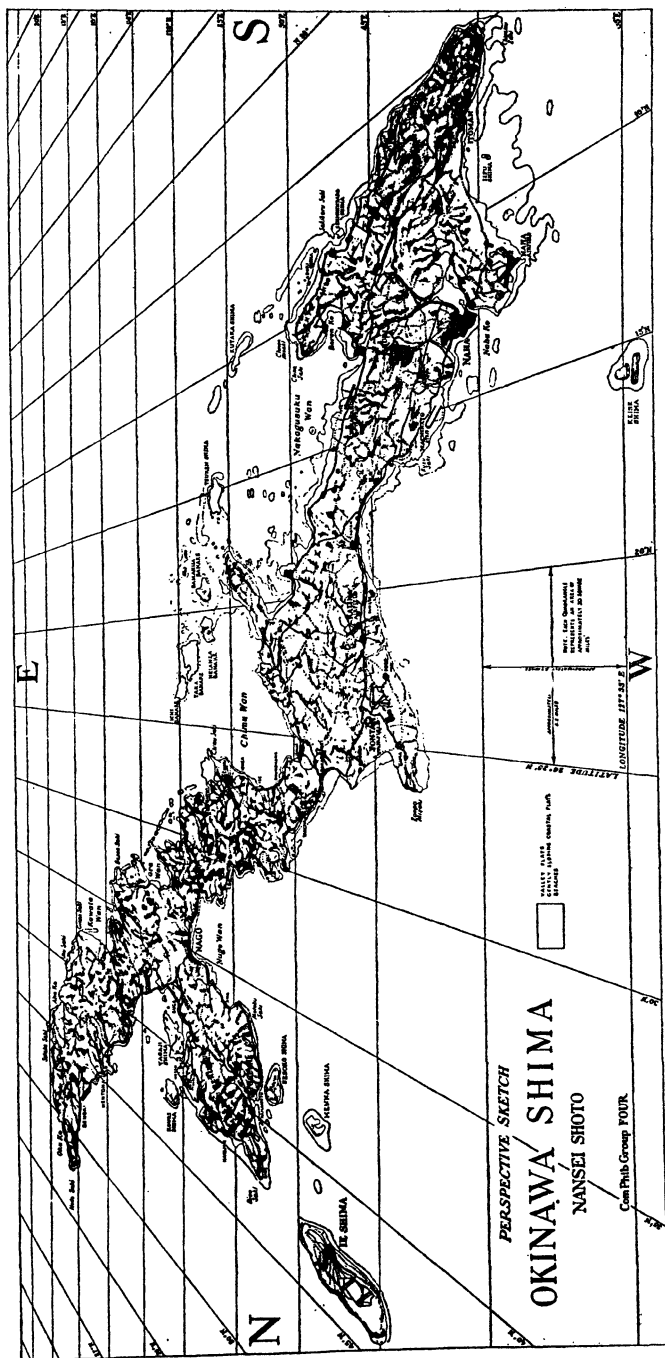


FIGURE 2.—Pre-invasion panoramic map of the island of Okinawa.

industry should also aid in providing food. In this connection, salvaged United States landing craft have been turned over to Ryukyu fishermen.

Efforts are also being made to rebuild other Ryukyu industries, and apparently the results have been satisfactory where raw materials and in some cases salvaged equipment are obtainable. The Military Government rehabilitation program envisages trebling the stone quarrying and woodworking production to meet high current needs; building up the cement, Panama-hat, and lacquerware industries for export; eventually developing silk production to meet the local demand; and bringing back the ceramic, brick, dyeing, sulfur, and coal output to prewar levels. The household crafts, such as mat making and linen weaving, went back into production with less difficulty than other industries.

As early as September 1945 temporary elementary schools were organized. By early 1947, enrollment was as high as in 1937. High schools and technical schools were being organized, and present labor laws require school attendance until 18 years of age (Japanese). School texts have been mimeographed and distributed. Certainly the curricula of present-day schools represent a decided change from prewar days. In addition to educating the youth, special adult classes have received practical instruction. Motor maintenance and repair, use of heavy equipment, and preparation of unfamiliar imported foodstuffs are examples of this training program.

Recently malaria, influenza, and trachoma have been the most prevalent communicable diseases. Before the war, malaria was endemic only in certain areas of the Ryukyus, but the thorough shuffling of the native population during and after the invasion has rendered the disease an island-wide problem. Mass immunizations for smallpox, dysentery, and diphtheria (see pl. 5, lower) have been carried out by Military Government authorities. The prevalence of intestinal parasites and filariasis in the native population needs the attention of a co-ordinated program, but will require sanitary measures to which the Ryukyuans are unaccustomed.

In early 1947, 25 Christian churches were holding services in the Ryukyus, with about 200 more members than in 1937. (See p. 396.) Attendance doubled by the end of that year. It will be interesting to see whether or not a Christian philosophy can be successfully grafted to the Ryukyu culture pattern.

The rehabilitation of the Ryukyu people is proceeding apace under American administration. The immediate goal is to make them economically self-sufficient. The ultimate problem is how to best facilitate the adjustment of a simple agricultural people to the modern industrial world.

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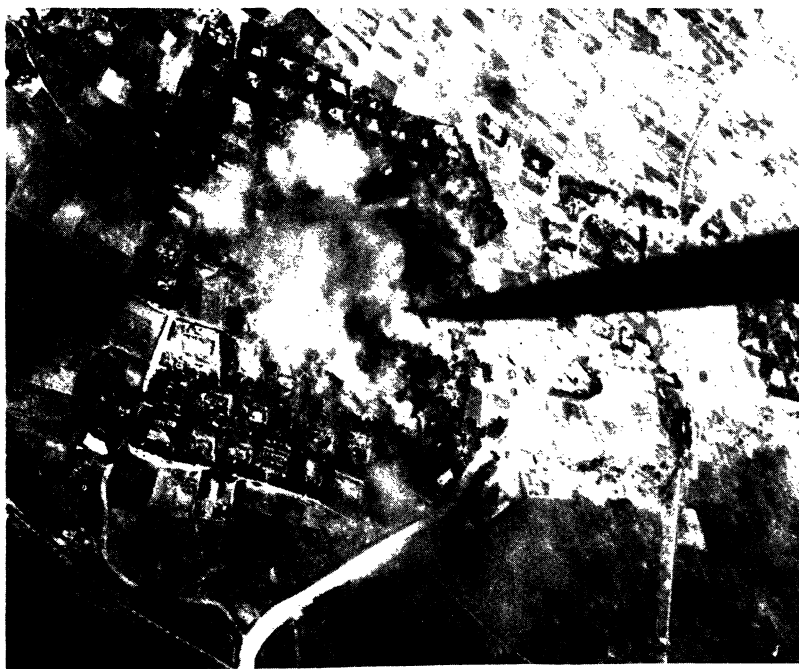
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1. Aerial view of the Bisha River and adjacent countryside in west-central Okinawa. The first invasion waves of landing craft are in the background. (Official U. S. Navy photograph.)



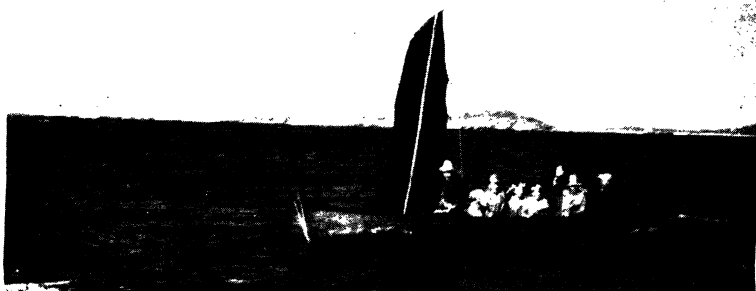
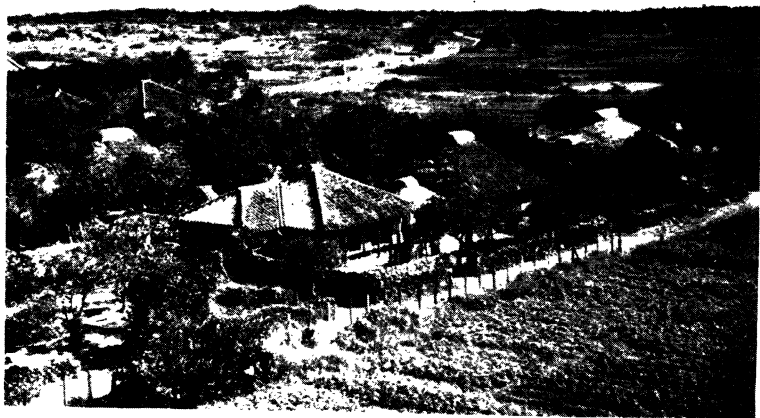
2. Aerial view of an Okinawan village. Many of the houses have been bombed or fired. (Official U. S. Navy photograph.)



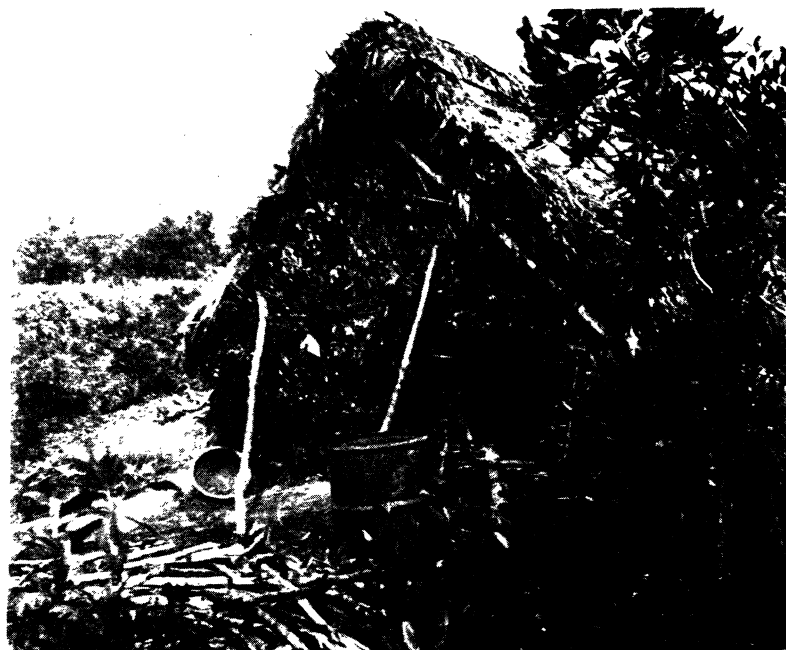
1. Okinawan women and children who just arrived at an M. G. civilian camp in the early days of the invasion. (Official U. S. Navy Photograph.)



2. One of the first M. G. civilian camps set up on Okinawa. (Official U. S. Navy photograph.)



Upper, native village on Ishigaki-Jima in the South Ryukyus; center, native sailing craft in the Iriomote Jima group; lower, concrete tomb from Okinawa. (Photographs courtesy J. Allen Chase, Leon Lewis, and A. C. P. Bakos.)



Upper, home of a Shinto priest at Kin, Okinawa; lower, temporary home of a refugee at Gimbaru, Okinawa. (Photographs courtesy J. Allen Chase and Leon Lewis.)



Upper, a group of lepers in the colony on Yagaji Shima, off northwest Okinawa; lower, school children of Kanna, Okinawa, being immunized for dysentery. (Photographs courtesy J. Allen Chase and Leon Lewis.)

PUZZLE IN PANAMA¹

By WALDO G. BOWMAN

Editor, Engineering News-Record

[With 8 plates]

A good many things came to an end when the atomic bombs exploded over Hiroshima and Nagasaki. And not the least of those things that were lost forever was our confidence in the security of the Panama Canal.

That fact is now being reflected in a comprehensive engineering study to determine whether the present Canal or any canal in the same or any other location can be made safe for our merchant and naval fleets in wartime. And, of equal concern, if not of the same grimness in consequences, is the problem of the adequacy of the Canal to meet the growing demands of peacetime shipping. It all adds up to a puzzle of first-order magnitude.

Nor is the puzzle simplified (although the scope for its solution is undoubtedly broadened) by the fact that the atomic bombs not only blasted confidence in the present Canal, but also raised up a ghost—that of a Panama sea-level canal whose earthly body was interred on June 29, 1906, when Congress adopted the lock-type canal favored in the minority report of President Theodore Roosevelt's board of consulting engineers. And to this sea-level canal ghost the present investigators may well repeat Hamlet's famous questions to the ghost of his father, "Be thou a spirit of health, or goblin damned? Say, why is this? Wherefore? What should we do?" Sea level or not, and if not, then what? That is the question, and the present puzzle in Panama.

Because a proper solution is of vital importance to every American, and of major interest to all engineers and construction men, a first-hand account of the progress of the studies was deemed timely and desirable. What the conclusions and recommendations will be is not now known, indeed will not be known until they are reported to Congress late this year (1947). But after 2 weeks in the Canal Zone talking to officials, witnessing tests, traveling the canal, clambering over

¹ Reprinted by permission from Engineering News-Record, vol. 138, No. 18, May 1, 1947.

its famous once-sliding banks, inspecting its locks and dams, and listening to scuttlebutt and rumor, a reasonably complete account of "*Isthmian Canal Studies—1947*" can be rendered. This is it.

OBJECTIVE AND PLAN OF THEIR STUDIES

The studies had their beginning on December 28, 1945, when Public Law 280, Seventy-ninth Congress, first session, was passed. In it Congress said to the Governor of the Panama Canal, "Tell us how we and the American people can best be assured of a ship crossing of the isthmus that will be safe from war hazards and of ample capacity for many years to come. Give us a recommendation for the best type of canal and the best route, no matter where located, in Panama or out." Included in the studies, of course, was to be a revaluation of the \$277,000,000 project to build a third set of locks, larger and removed some distance from the present pair, begun in 1939 (*Engineering News Record*, September 14, 1939, p. 330) and suspended because of the war in 1942 after most of the necessary excavation had been completed.

Maj. Gen. Joseph C. Mehaffey, Governor of the Canal Zone, and himself an Army Engineer officer with a long record of service on the Canal, lost no time in initiating the authorized study, for which about \$5,000,000 has been provided. Assigning the task to the Canal's special engineering division, which was created to handle the third locks project, he appointed Col. James H. Stratton as supervising engineer. Enjoying an outstanding reputation as one of the ablest technical men and administrators in the Corps of Engineers, Colonel Stratton was soon successful in assembling an unusually capable staff of civilian engineer specialists to head up the various phases of the work. Supplementing his own organization with a board of eminent consulting engineers to afford continual guidance and advice, he went to work. And as need developed, individual specialists from private life and from the Office of the Chief of Engineers were called in while, in addition, special research contracts were awarded so as to bring the nation's best talents to bear on the problem.

The procedure of the studies is simple and effective. Investigations of each particular subject—routes, lock design, dredging, drilling and blasting, soil mechanics, flood control, hydraulics, construction planning, to name a few—are carried out by the staff specialists through their own research and analysis and aided by the outside research contracts. As the study of each phase or subject is completed, a report or memorandum is prepared. Then, at the periodic meetings of the consulting board, the section heads present the memos (No. 183 having been reached on March 1, 1947), which are approved, turned down, or returned for further study.

The eventual result of this whittling and sifting will be a set of conclusions from which a final recommendation can be made to the

Governor by Colonel Stratton and the board. If the Governor accepts it, as is probable since he keeps in close touch with the work even to taking part in the consulting board meetings, the recommendation will be presented to the War and Navy Departments for review, and will then go to Congress. What happens after that in the way of actual design and construction is up to the law makers, the President, and the American people.

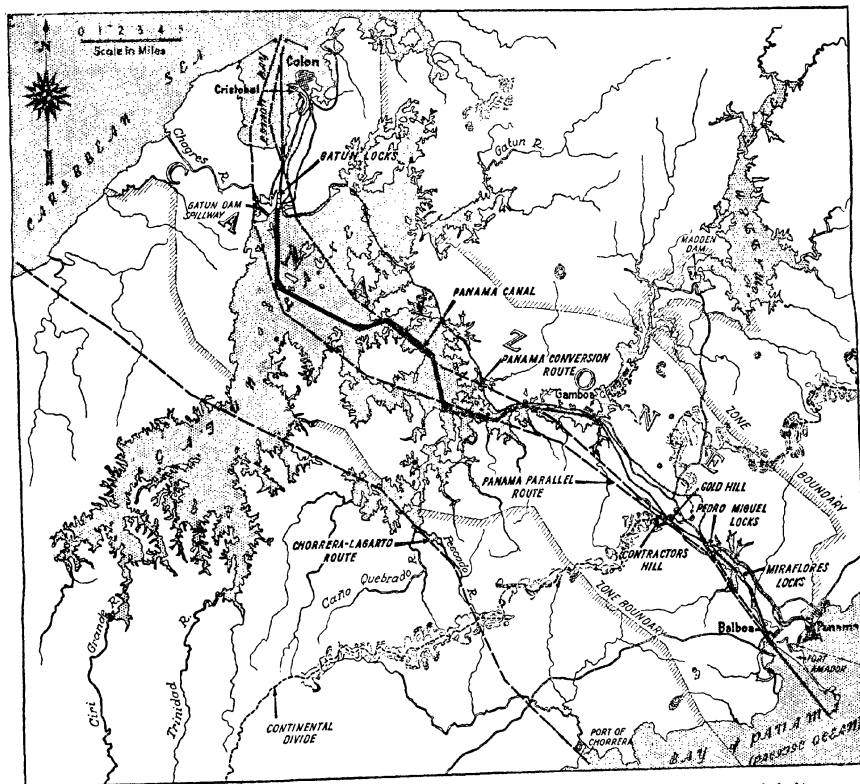


FIGURE 1.—The Panama Canal and three of the alternate routes in its vicinity whose engineering feasibility and relative cost and security are under investigation.

Considering the study procedure and the topnotch technical talents of the men engaged on the work, and observing their earnestness of purpose and high sense of responsibility, one cannot but feel that the recommendation will be honestly arrived at, technically sound, and unaffected by frivolous whims or superficial reasoning. There almost surely will be those who will disagree with the recommendation, but none except the carelessly biased or the unscrupulous who would question its integrity.

Since Congress ordered examination of all possible routes, the obvious line of attack was to study each possibility in turn to the point where it eliminated itself from consideration because of lack of water for lockages, too great length, poor terminals, excessive excavation, lack of security, and other applicable reasons. If followed thoroughly and fairly, this procedure should leave for final consideration the best type canal on the best route. To achieve a degree of comparison among all routes a hypothetical canal was initially assumed in each case, with a bottom width of 500 feet and with side slopes of 1:1.

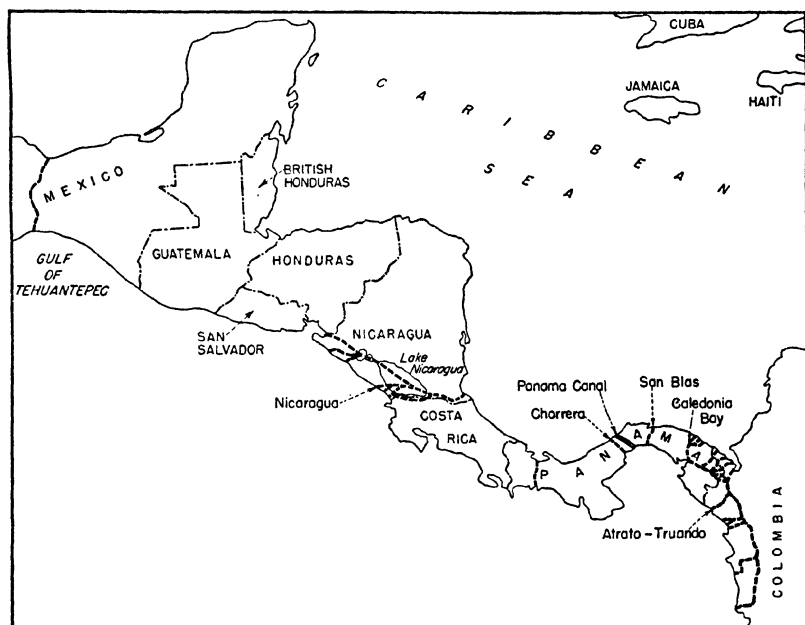


FIGURE 2.—Engineering and construction studies initially encompassed 22 isthmian routes from Mexico to Colombia. Those named plus two others—the Panama Parallel and Panama Conversion Routes near the present canal—warranted the most study.

A total of 22 routes was examined, as shown on the map, figure 2. Including practically all of the routes that have been proposed or studied over the past century or more, the list contained some that were readily dropped from consideration as patently impractical, others that required more detailed study, and a few upon which special field work was deemed necessary. Indicative of routes easily eliminated was Tehuantepec in Mexico, which has the advantage of being nearest the United States, but would require $6\frac{1}{2}$ billion yards of excavation for a sea-level canal and 15 lifts of about 39 feet each for a lock canal. Another even more easily eliminated was Chiriqui in Panama near the Costa Rican border where an even greater yardage would have

to be removed to create a sea-level canal and where there is no water at high elevation to supply a lock canal.

MOST STUDY GIVEN 4 OF 22 ROUTES

Elimination of the patently impractical routes left four, outside the immediate area of the existing canal, for further study—San Blas (named for an area and an Indian Tribe) and Caledonia Bay, for either a sea-level or a lock canal; Atrato-Truando (named for the two rivers that it follows) for a sea-level canal; and Nicaragua (with Pacific terminus at Brito) for a lock canal. Except for Nicaragua, the available field data were less than desirable to permit a satisfactory analysis. Field surveys were, therefore, undertaken, using both ground and aerial mapping procedures. Such ultramodern aids as two-way radio communication between ground and air, radar profiling from the planes, mapping cameras that take pictures at 1-second intervals, and special ground altimeters provided much better data than were available before, so that the decisions that will be made as to these routes should be correspondingly better.

Whether San Blas, Caledonia Bay, or Atrato-Truando will be shown to have potentialities comparable to Nicaragua, whose merits have long been recognized, remains to be seen. However, a sea-level canal at Nicaragua is probably ruled out because the necessary draining of Lake Nicaragua would deprive the country of an important body of water and probably alter its climate. The lock canal, favorably reported on in 1931 by the late Gen. Daniel Sultan, is still one of the best possibilities if a supplementary canal at another location than Panama is deemed necessary. Its cost now could easily be twice the \$722,000,000 estimated by General Sultan, and its safety from modern weapons of destruction would be no greater than that of the present canal, but such disadvantages are relative, and might, in a comparison with other routes, be worth accepting.

IMPROVING THE PRESENT CANAL

Obviously, any new route for a canal must be far superior to the present one to warrant serious consideration, unless, of course, we are to have two canals, a possibility that cannot be ruled out and one which it is understood has been considered in connection with some proposed routes near the present canal. These will be described later in this article, but first the proposals for improving the present canal need to be considered.

The existing Panama Canal has many advantages. It has operated successfully for over 30 years. Its length is comparatively short. Its total lock lift of 85 feet is moderate. It has ample water supply. Its terminals are established communities with efficient harbor and port facilities. It represents one of our proudest national possessions, and

is among one of our largest capital assets. What then does it lack?

First, its present capacity is estimated to be inadequate for commercial shipping after 1964, and its locks are not wide enough for modern and future naval vessels. (It was to overcome these disadvantages that the Third Locks Project was initiated, providing lock chambers 140 feet wide as compared with the present 110 feet.) Second, it may not be safe against modern bombing. These were the items—capacity and security—on which Congress asked to be assured.

Insofar as capacity is concerned it is certain that the lockage load of the present canal can be increased. The Third Locks Project would do it. Replacement of the existing locks with new ones of larger dimensions and increased efficiency would also do it. Even the installation of a type of gate that could be removed for maintenance and repair (while a temporary gate replaced it) would greatly increase capacity by reducing the present overhaul time that keeps one lane of the existing locks out of service 4 months every 2 years.

The present investigators, however, are believed to favor a fourth way as best meeting the needs of increased capacity and security for the present lock canal. This is by means of the so-called Pacific terminal lake plan in which all lock lifts on the Pacific side would be concentrated in the vicinity of Miraflores; in effect this would eliminate the single-life lock at Pedro Miguel, and raise Miraflores to elevation 85 feet so that it would become an integral part of Gatun Lake, connected to it by Gaillard cut.

To understand this plan, as well as ones proposed to convert the lock canal to one of the sea-level type, it is necessary to have the lay-out of the present 45-mile long canal clearly in mind. Briefly, it consists of a large artificial lake, called Gatun Lake, at elevation 85 feet above sea level, reached by three lock lifts on both the Atlantic and Pacific sides. Ships entering from the Atlantic side, for example, are raised in the Gatun locks whose three lifting chambers, each 110 feet wide and 1,000 feet long, are continuous and in the same structure. They then traverse the lake for some 20 miles in a winding channel 500 to 1,000 feet wide that follows the former valley of the Chagres River whose waters have been impounded to form the lake.

Leaving the lake, ships enter Gaillard cut, 300 feet wide at the bottom and 7 miles long, emerging to enter a single-lift lock at Pedro Miguel, which drops them 30 feet to Miraflores Lake at elevation 55 feet above sea level. Miraflores Lake is about a mile long, closed at its southern end by Miraflores locks, a two-lift structure in which the ships are lowered to the level of the Pacific Ocean, which is 7 miles farther on. It will be recalled that the single-lock lift at Pedro Miguel was separated from the twin lifts at Miraflores (instead of putting all three together as at Gatun) because of poor foundations at the north end of the Miraflores site. Some of the early canal engineers did not

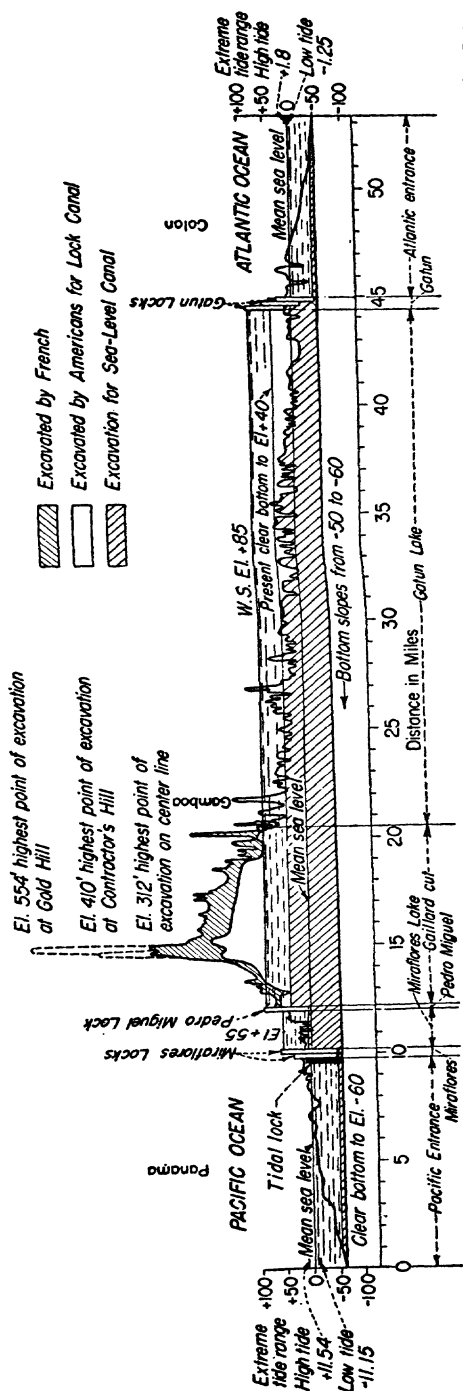


FIGURE 3.—Profile of Panama Canal indicates both present lay-out of locks and lakes and the excavation that would be required to convert it to a sea-level canal with only a tide lock at the Pacific entrance.

agree that the conditions were as "poor" as represented, and many concur in that view today.

IMPROVING THE LOCK LAY-OUT

The Pacific terminal lake plan referred to above, advocated by several engineers at the time the present canal was being planned, and before that by one of the early French engineers, would increase the capacity of the canal by putting Miraflores Lake between the last lock lift and the entrance to Gaillard cut, thus providing an anchorage area for Atlantic-bound ships above the locks in case the cut were too foggy to navigate. Now ships have to wait below Pedro Miguel lock or out at sea until the cut is clear.

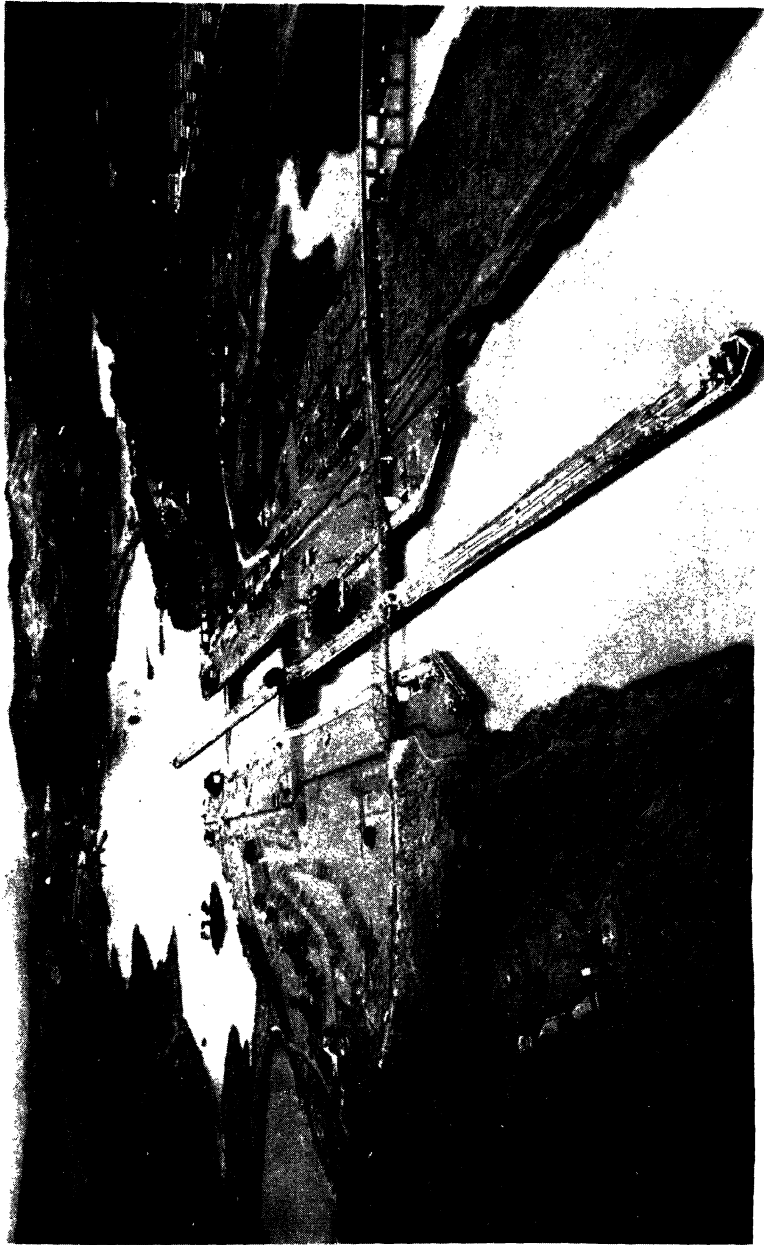
The theory is that in bad weather a good many ships could accomplish the slow process of locking-through whereas now the locks are idle if the cut is shrouded in fog. In any such improvement scheme, of course, the new locks could be built of increased size and efficiency (some of as much as 200 feet width, 1,500 feet length, and of two-lift design, having been studied), which would further augment the canal capacity. Also, most of the schemes studied have contemplated raising the level of Gatun Lake from elevation 85 to elevation 92 to increase the supply of lockage water.

As to increased security, the supposition apparently is that a concentration of all lock lifts in one place would also permit more effective concentration of protective facilities and defensive measures. Additional security could also be achieved by separating the two lanes of any new locks safe distances from one another.

CONVERSION OF CANAL TO SEA LEVEL

But is any type of lock canal secure in the sense that Congress used the term in the request for the study? The decision of the investigators on that point is vital. One has only to recall the movies of the Bikini atomic bomb tests, where a column of water that looked to be half a mile across was thrown several thousand feet in the air, to visualize what would happen to a lock. Or look at the hole in the ground caused by the explosion of a hundred pounds of dynamite and interpolate to the equivalent effect of millions of pounds of TNT. And once a hole were breached in a lock or one of the impounding dams, the lake would drain out, and no amount of repairs could restore the canal to service until rainfall and run-off refilled the lake. It is a sobering thought, and one that cannot be ignored under the mandate that Congress wrote into Public Law 280.

One way to eliminate the danger is to eliminate the lake and the locks, to convert the canal to a sea-level waterway. And there is ample evidence that the investigators are studying the possibilities long and



Pedro Miguel Locks, Panama Canal. (Photograph by Press Association, Inc.)



Locks in the Panama Canal, such as these at Gatun, whose future adequacy and wartime safety are in question. (Official U. S. Navy photograph.)



Gaillard Cut, whose slides have caused so much trouble, would again be the scene of major construction if any scheme involving widening, deepening, or straightening is recommended. Present knowledge, it is believed, could cope with the slide menace. (All photos by author except as noted.)



Third Locks project, begun in 1939, whose questioned adequacy to increase capacity and security of the present canal brought about the present investigation. Maps in figure 4 indicate location of project relative to present locks: above photographs show completed new lock cuts as they exist today. Left, cut at Pacific end looking across plug that separates it from Gatun Lake; right, cut at Atlantic end looking seaward from plug that separates it from Miraflores Lake.



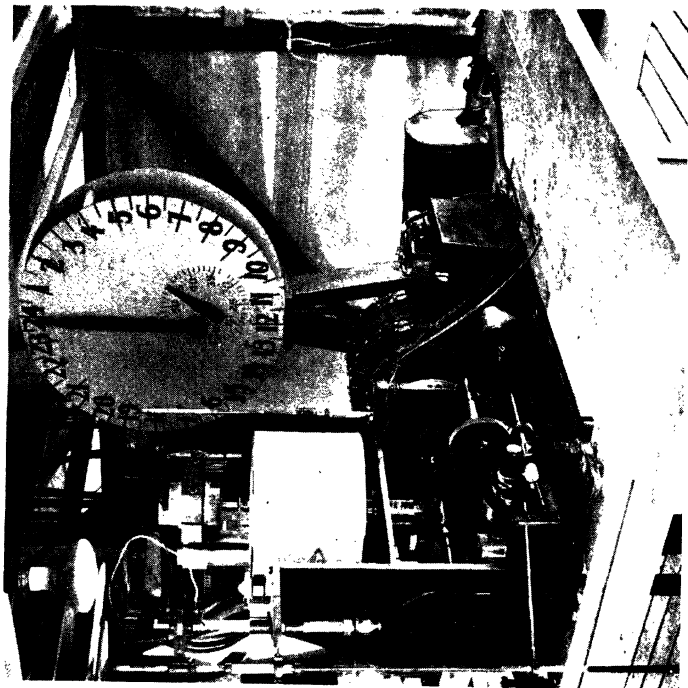
1. Test drilling and blasting at unprecedented depths of 135 feet below water surface are being carried out from a barge plant in the approach to the Third Locks Cut on the Atlantic side.



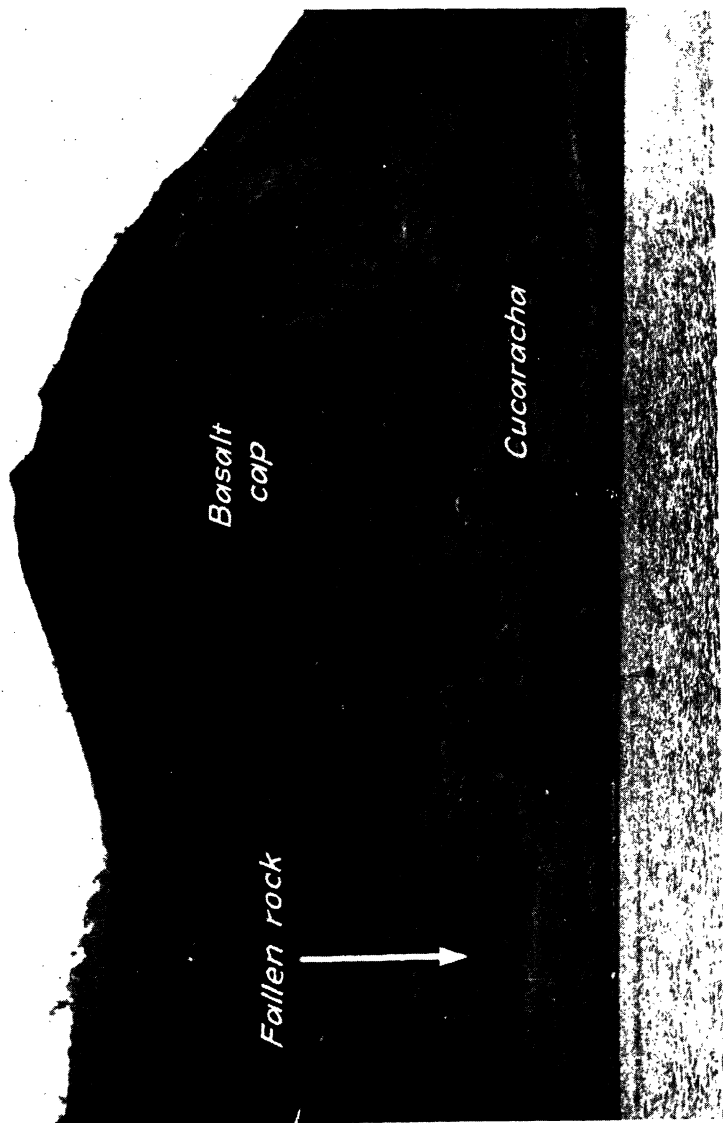
2. Tide-control structures simulated in the half-mile-long hydraulic model of a sea-level canal built to the alignment of the existing canal. To the left is the tide lock. The man is standing over the navigable pass gate, and to his left is the water-control structure. During tests the model is covered with canvas, as at the right, to shield it from the wind.



1. Col. James H. Stratton in charge of "Isthmian Canal studies—1947" on an inspection of the model of a sea-level canal that has been constructed in the Canal Zone.



2. Tide-producing mechanism at each end of the hydraulic model. The cam at the left, whose outline represents a polar plot of the tides in a 24-hour period, is moved by a time device and actuates a float valve which admits the proper amount of water to the canal. Tide variations are recorded on graph paper wound on the drum.



One type of slide on Panama Canal is caused by weight of hard basalt cap on soft Cucaracha formation, creating a tendency for the latter to heave in bottom of canal. In future construction the basalt cap would be removed.



Varying geology along the Canal is emphasized by formations in the Third Locks Cuts. Left, Gatun sandstone at Atlantic end; right, columnar basalt at Pacific end.

carefully. For one thing, they have built a half-mile-long model of a sea-level canal to the alignment of the present lock canal to test the effect of tides on currents. They have set up criteria for improved alignment, and are having the Navy study the behavior of ships in canal models built to these criteria in the David W. Taylor testing basin at Carderock, Md. They have let design and study contracts in the United States for the development of dredges that can dig at unprecedented depths, as would be necessary in Gatun Lake. And they have recently tested tide-gate and navigation-pass lay-outs in their sea-level model in the Canal Zone. All these activities point to unusual concern with the possibility of converting the present lock canal to one of sea-level type.

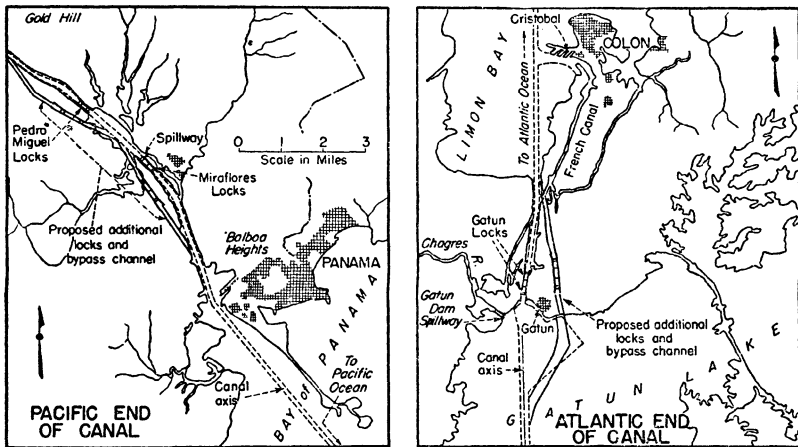


FIGURE 4.—Maps indicating location of Third Locks Project, begun in 1939, relative to present locks. (See plate 4.)

Of the numerous ways by which the conversion could be effected, at least two are known to have been studied, one involving lowering Gatun Lake to sea level in stages, the other lowering it in one operation. They have been called the stage-lowering plan and the deep-dredging plan.

TO SEA LEVEL BY STAGES

The essential element of the plan for lowering Gatun Lake to sea level by stages is a temporary lock at each end to permit the passage of traffic at each lowering stage, first from elevation 85 to 50; second from elevation 50 to 20; and third from elevation 20 to sea level. The location for these temporary or conversion locks is ready-made in the cuts that were dug for the Third Locks Project, $\frac{1}{2}$ mile east of the existing Gatun locks at the Atlantic end and $\frac{3}{8}$ mile west of Miraflores locks at the Pacific end, although some widening might be re-

quired if locks wider than the 140 feet originally planned were deemed necessary. Should the third locks idea be abandoned, this plan thus provides an effective way to save a large part of the investment already made in that project.

Two variations of the conversion locks have been studied, one using a single-lane lock, the other a double lane. Since two lanes for traffic must be maintained during all lake-lowering stages, adoption of the single-lane conversion lock would require also that first one lane and then the other of the existing locks be modified to operate at the lower lake stages. This would entail a construction operation of considerable magnitude and difficulty, since the center wall between the existing locks would have to be underpinned during the time that the upper chamber of one lane was being removed so that this lane could be available for traffic when the lake was lowered to elevation 50. Later, when the other lane was cut down from elevation 85 to elevation 20 to serve traffic at this lake level, the same ticklish operation would have to be repeated. As a corollary of the construction difficulties of this method there would be considerable risk, for a failure of the center wall might result in draining the lake.

The two-lane conversion plan is both simpler and more certain, for it would permit complete abandonment of the existing locks during the lowering stages. The idea would be to make the conversion lock of one-lift design, capable of being used at all stages from elevation 50 to sea level. While the lock at the Atlantic end, for example, was being built in the third locks cut, seaward from the unexcavated plug that separates the cut from the lake, the deepening of the channel in the lake would be carried out. This would entail dredging to a maximum depth of about 85 feet (present water surface, elevation 85, minus future water surface, elevation 50, equals 35, plus a 50-foot channel equals 85 feet). Such a depth is well within the capabilities of contemporary dredging equipment.

Once the channel was deepened, the plug ahead of the conversion lock would be blown out, and the lake water surface rapidly lowered to elevation 50. Then, with the two-lane conversion lock in constant service, the channel could be deepened as the water surface was progressively lowered until the bottom of the excavation reached project grade of 50 feet below sea level (and increasing to 60 feet at the Pacific end because of the greater tide variation there).

At the Pacific end the conversion plan would be only slightly different. The single-lift conversion lock would be built in the third locks cut at Miraflores. When it went into service, as the Gatum Lake water level was dropped to elevation 50, Pedro Miguel lock, which operates between elevation 85 and elevation 50, would be high and dry. Since the third locks cut at this location was hardly more than begun before that project was shut down, a bypass around the existing lock would

have to be provided. This, however, would be a part of the required channel deepening and not lost motion.

Finally, with respect to any of the stage-lowering plans, there is one special requirement to be met that would involve extra cost and construction difficulty. This is the provision of salt-water pumping plants to make up a deficiency of water for lock operation after Gatun Lake is lowered to elevation 50. Estimates indicate that such plants might have to aggregate over 4,000 second-feet in capacity.

DEEP-DREDGING PLAN

All the expense and trouble of conversion locks could, however, be eliminated if dredges could dig as deep as 135 feet below the water surface, i. e. from elevation 85, existing lake level, to elevation -50, the required sea-level channel depth. It is the great appeal of this plan, as to simplicity and to probable lessened cost, that has led the investigators to award the special dredge-development contracts. Should this plan prove feasible it would only be necessary to dredge channels in Gatun and Miraflores Lakes to elevation -50, and then knock out the protective plugs in the third locks cuts, draining the lake. There would be 8 to 10 days interruption to canal traffic while the plugs were being removed and the channels cleared of debris, but after that the sea-level canal would be a going concern.

Simple in concept though it is, the deep-dredging plan raises some puzzling questions. One of these is basic: Can dredges be designed and built to dig at 135-foot depths, and fast enough to be practicable from a cost standpoint? To find out, two contracts have been awarded, and to date the results are encouraging.

One of the contracts, covering both the design of a hydraulic cutter head dredge and studies and estimates of a construction plan, is held by a combination named Panama Contractors and consisting of Gahagan Construction Co., Standard Dredging Co., and the Atlantic, Gulf and Pacific Co. Their contemplated dredge is said to have a 46-inch suction and a 40-inch discharge, and to incorporate the unique feature of a booster pump set about 65-foot down on the 185-foot long boom. Lifting and swinging gear would be of unprecedented size, and large buoyancy tanks would help support the boom. The spuds on this huge machine would be 150 feet long, the lower 80 feet of which telescopes into the upper part as required for adjustment.

The second deep-dredge contract covers design only of a bucket ladder dredge and is held by the Yuba Manufacturing Co., specialists in these types of dredges. Although ladder dredges with $\frac{2}{3}$ -yard buckets have operated at 124-foot depths in California gold-mining work, nothing approaching the high capacity and 135-foot depth required for the Panama dredging has ever been built. Buckets as large as 6 cubic yards were investigated, but it is believed that the

greatest efficiency, relating power input to excavation production, can probably be attained with 2-cubic-yard buckets. Designed so that six such buckets would always be in contact with the bottom, a ladder dredge, it is claimed, would provide an efficient means for digging at 135-foot depths.

Large dipper dredges, although impracticable for such deep work, can be used for slightly shallower digging, particularly in hard material, and the Bucyrus-Erie Co. holds a third design contract for such a machine capable of working at a 90-foot depth. With a 20-yard bucket for hard digging and a 30-yard size for softer material, the use of four 250-horsepower motors on the main hoist of such a dipper dredge, supplemented by a 165-ton counterweight, would provide speedy operation and large production. For all the proposed dredges there seems to be a preference for self-contained Diesel-electric power units rather than relying on an outside energy source. The cost of any one of the dredges, it is rumored, might run as high as \$5,000,000.

Another important consideration in the deep-dredging plan relates to drilling and blasting procedures under such great depths of water. Such work has never been done before, and powder-company estimates of the amount of explosives required are quite variable—from 2 to 4 pounds per cubic yard of rock removed as compared to conventional charges of $\frac{1}{2}$ to 1 pound. Tests now under way in the Atlantic approach to the third locks cut, however, prove that the Gatun sandstone, a relatively soft rock, can be broken to sizes for handling by any of the contemplated dredges with only slightly over 1 pound. Similar deep-drilling and blasting tests are planned in the hard basalt rock that prevails on the Pacific side.

Powder costs could, however, be doubled or tripled without any important consequence. Getting the holes down is what will run into big money. The actual drilling at great depths adds no new difficulties, according to the present tests, so that the crux of the drilling question will be speed and how to attain it; whether by exceptionally long drill steel or by the development of techniques to connect more conventional lengths rapidly; whether by a few supersize drill boats or by large numbers of smaller ones; and whether by rotary or percussion-type drills.

TIDE CONTROL

Any sea-level canal, no matter how or where built, will require a number of auxiliary structures and special construction operations. Thus, structures that will exclude unwanted currents, as from tides or from entering rivers, are of prime importance; while the necessary canal alignment to assure ease of navigation and the required side slopes to obviate slides will affect dry as well as wet excavation practices.

A great deal of design effort and model study has been expended on the subject of tide control, since the large difference in tide ranges—20 feet maximum on the Pacific side and only 2 feet on the Atlantic—would be expected to generate a considerable current. Actually the maximum velocity has been shown on the sea-level model to be only 4.2 knots, and interestingly enough this occurs at the Atlantic end and farthest removed from the high Pacific tides that create it. Nevertheless, this is considered excessive for ordinary merchant-ship operation in a canal much of whose bottom and banks would be rock, as contrasted with the sand in the Cape Cod Canal where such a velocity occurs, and means are being sought to reduce it.

One method, and the one proposed in the majority report on the original canal in 1904, is to use a barrier dam and locks. But since it would take time to lock every ship entering or leaving the canal, even though the average lift would be only about 6 feet and the maximum 10 feet, the present investigators have been studying a “navigable pass” arrangement similar to those used on the Ohio River by which ships could pass between canal and ocean at certain tide stages without using the locks. Not only would this speed canal operation, but the navigation-pass lay-out would provide maximum security from bombing since, if hit, the closure dam could be quickly dragged out of the way. Then the canal could be used without tidal regulation, which is deemed practicable in an emergency.

An opening could of course be cleared through a barrier dam and lock, if they should be bombed, but it would be a time-consuming operation. Moreover, it is believed to be the present thinking of the investigators that use of the navigable pass would so familiarize the pilots with open-water operation of the canal that they would be ready for any emergency, whereas the lock-and-dam plan would not permit this advance training.

ELEMENTS OF NAVIGABLE-PASS PLAN

The proposed navigation-pass lay-out would include three elements—the pass equipped with a movable dam, a set of locks, and a gated water-control structure. Just how these would be arranged would depend upon the location chosen for the tidal-control works. One of the arrangements tested on the sea-level model places the tide lock, equipped with sector-type gates, in the third locks cut at Miraflores; the navigation pass, with a 750-foot-wide opening, in the approach to the present canal; and the water-control structure, of whatever width necessary, beside it. An interesting aspect of this arrangement is that the tidal lock could temporarily be increased in height and used as the conversion lock should the stage-lowering plan of canal conversion be adopted.

From the lay-out on the sea-level model it is apparent that the designers are thinking of a retractable-type dam across the navigation pass. And, since the dam must be capable of withstanding a 10-foot hydrostatic head on either side, a triangular cross section steel box has been chosen. Mounted on rollers, the prototype dam would be 80-foot high, extending 60 foot below and 20 foot above the sea bottom. One contemplated way of operation is by hydraulic pressure, introducing water into the retracting chambers to close the dam and evacuating the water to open it.

The water-control structure involves a normal tainter gate set-up, its purpose being to bring the pool elevation inside the navigation pass to the tide elevation outside as early in the tide cycle as possible so that the navigation dam can be open the maximum length of time. Under the tentative criterion of a maximum permissible current of 1.8 knots (3 miles per hour) the tests indicate that the navigation

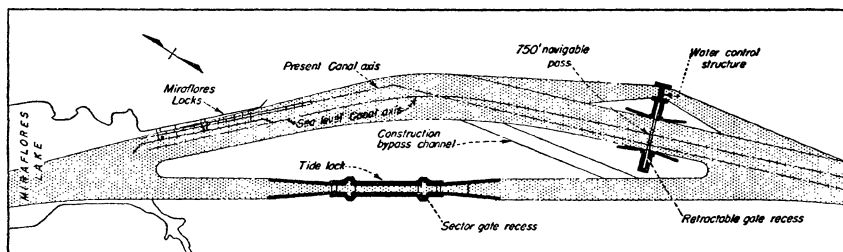


FIGURE 5.—One of the tide-control schemes studied locates the necessary structures in the vicinity of the present Miraflores Locks. A tide lock is placed in the existing Third Locks Cut, a navigable pass, with retractable-type gates, in the present canal, and a tainter-gate water-control structure in an adjacent bypass channel.

pass can be used on an average of one-third of the time, or from $1\frac{1}{2}$ to $3\frac{1}{2}$ hours out of each 6-hour tide change depending upon the time of year.

How the tidal variations in the model are produced is of interest. The model itself, built to a geometric scale of 1:100, is a half-mile-long slab of 4-inch concrete laid to the alignment of the present lock canal and supporting concrete curbs to simulate the canal slopes and define the channel. At each end are basins representing Balboa and Cristobal Harbors, and to these a constant amount of water is supplied. Then, by wasting varying quantities of this water through an electrically operated gate, the desired tide elevations in the harbors are obtained.

The waste gate is controlled by a special tide apparatus, chief element of which is a cam whose shape was scribed by a polar plot of the tide elevations at each hour of the cycle. Connected to a time mechanism this cam keeps the waste gate as far open or closed as

the tide at a particular time in the cycle requires. Water levels in the canal during the tests are measured by automatic recorders, and velocities by pygmy current meters or by time-exposure pictures of floating confetti.

FLOOD CONTROL

One of the requirements of a sea-level canal will be complete exclusion of entering streams. It would be expected that flood flows would have to be kept out, but recent tests indicate that even smaller flows, which could otherwise be carried by the canal, create objectionable currents. Salt and fresh water do not mix quietly.

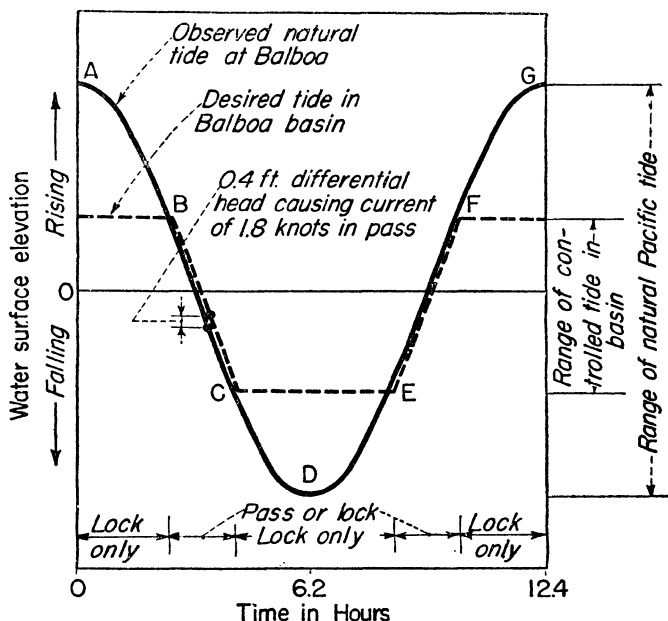


FIGURE 6.—How tide-control structures would be operated at various stages of tide cycle. Between B and C flow would be out of canal through water-control gates, and between E and F the flow would be into the canal. During these periods ships could use the pass.

Were the Panama Canal to be converted to sea level, such important rivers as the Chagres and the Gatun from the east and the Trinidad and Cano Quebrado from the west would have to be blocked and the water carried to the sea through diversion channels. A dam would no doubt be required at Gamboa on the Chagres to impound the excess run-off of that stream, which is not now held by the existing Madden Dam farther upstream. But it would probably not have to be as high (in view of the supplementary effect of Madden) as the one proposed for the same location in some of the original canal plans and which then caused so much discussion with respect to foundations

and type of structure. Moreover, our present knowledge of dam building generally and of foundation conditions at the site is far advanced over that of 40 years ago.

IMPROVED CHANNEL ALIGNMENT

One of the necessities for a safe canal of ample capacity is an alignment that permits easy handling and maneuvering of ships, and the present canal is far below a reasonable standard in this respect. The investigators have, therefore, devoted much attention to this subject, since it is appropriate to any canal route that is to be chosen.

As a target to shoot at and test, rather severe criteria were set up. These include a 500-foot-wide channel bottom, a 50-foot depth, curves of 20 degrees maximum deflection angle (some of the present ones are near twice that), sight distances on curves of not less than a mile, and 5-mile tangents between curves. These dimensions and others, both more severe and more conservative, are being tested in the Navy model basin at Carderock, Md., where the handling of model ships under various current conditions will also be studied. When conclusions are reached, the outdoor sea-level model in the Canal Zone will be rebuilt to the new criteria as a further check on performance. Since all studies are based on providing ample canal capacity up to the year 2,000 such modern and future navigation aids as infrared lights, fog-dispersal equipment, and radar and electronic devices are not being overlooked.

Whatever the alignment and dimensions chosen, they will materially affect the cost and construction methods of a canal, lock or sea level, since a greater or lesser bottom width or degree of curvature brings different geological formations into the picture with their differing side slopes that are safe from sliding.

GEOLOGY POSES MANY PROBLEMS

The area traversed by the present canal is noted for its upside-down geology, hard rock occurring regularly on top of soft material. It was the weight of this cap rock that initiated much of the disastrous bank sliding in the early days of the present canal, and great care is being taken to avoid any return engagements on future construction. Evidence of the seriousness of this situation is contained in the figures of the amount of slide material removed from the present canal: 23 million yards before water was turned in in 1913, and about 50 million yards in the following 10 years.

Every opportunity is, therefore, being used to gain new knowledge through tests and study of past experience. Many data were collected during the third locks design and construction, and continued maintenance of the canal banks for over 30 years has produced many more.

must be quite flat, 1:5 or more. For safety and eventual economy, much of the overlying hard rock would have to be removed.

The third locks cuts indicate that Gatun sandstone will stand on a 6 vertical to 1 horizontal slope, and that 12:1 is safe for agglomerate and basalt: for the latter, berm widths and spacing criteria have also been established. Extensive loading tests have demonstrated that Cucaracha will safely carry 6 tons per square foot, while the harder Culebra, upon which the Pedro Miguel locks are founded, will carry 15 tons. It is facts such as these that give the investigators confidence in designs and construction methods being assumed for the purpose of their estimates.

As to devising actual construction methods, the present studies are going only so far as is necessary to prepare the cost estimates for construction periods of either 10 or 15 years. It is, nevertheless, understood that one of the most promising possibilities for moving the huge quantities of dry excavation involved has been shown by the studies to be a combination of batteries of 30-yard shovels and barge disposal. Some recasting of material by draglines would be necessary to reach the barges, or this could be largely eliminated by digging auxiliary channels into the banks through which the barges could be towed to within reach of the shovels. With a half billion yards of dry excavation to be handled large and expensive plant lay-outs are obviously justified.

TWO CANALS IN PLACE OF ONE

Earlier in this article mention was made of the possibility of a recommendation that would provide for building a new sea-level canal while at the same time the present lock canal would be kept in service. San Blas, Caledonia Bay, and Atrato-Truando were among the possible locations, but there are also routes near the present canal, and particularly one known as the Panama Parallel Route, that have also been seriously studied.

This Panama Parallel Route, whose alignment corresponds closely to that of the present canal except that it eliminates the big bends in the latter, is an original conception of the present investigators growing out of their studies of several routes having a Pacific terminus in Chorrera Bay a short distance outside the west boundary of the Canal Zone. One of these routes crosses the isthmus to the small town of Lagarto and is entirely outside the Zone. It has the advantage of offering dry excavation for the major part of its length, but the yardage would be formidable and the construction of new ports and harbors at both ends would entail tremendous expense, with Lagarto being practically in the open sea.

To eliminate the problems at Lagarto, two other Chorrera routes with Atlantic terminals near those of the present canal in Limon Bay were studied, followed by the next logical idea of shifting the Pacific terminus from Chorrera to the vicinity of Balboa on the present canal. Thus the Panama Parallel Route came into being.

A common element of all these routes was a crossing of Gatun Lake that would be blocked off by barrier dams, which would also provide flood protection from the various lake-feeding streams. By digging the other sections of the canal first, the resulting spoil could be used to build the dams, after which the Gatun Lake sections could be excavated in the dry behind their protection.

This idea has great appeal, its principal drawback being, of course, the tremendous dam-building job involved, since the total barrier dam length would exceed 14 miles. A conventional cross section of say 100-foot top width would not be too serious, but if this were increased 10, 20, or 30 times to provide security against modern weapons, grave doubts arise as to the advisability of the scheme. Nevertheless, once built, it would undoubtedly represent a reasonable solution of the problem that Congress set up. In the final analysis, also, it will have to compete with one of the Panama conversion plans on the basis of cost.

THE SITUATION SUMMARIZED

What then are the possibilities of solving this puzzle in Panama? What considerations must be resolved to come up with a recommendation for a canal that will best meet the requirements of security and ample capacity set up by Congress? Among the obvious ones are sound engineering, practicable construction, and minimum possible cost. To which must be added resistance to or possible protection from the destructive effects of present and future weapons of war. Adding up these considerations as they apply to each of the proposals and then comparing the results is the present task of the investigators. It is futile, and it would be improper, to anticipate or speculate upon their conclusion, but a few applicable facts will serve to summarize the situation as it now exists.

There are four routes removed from the present canal and three in the vicinity of it whose merits must be weighed. Of the former, three are sea-level routes whose yardages, estimated on a 1:1 bank slope assumption are as follows: Atrato-Truando, 1,590 million; San Blas, 1,520 million; and Caledonia, 1,260 million. What these yardages would prove to be were sufficient knowledge available to use geological slopes in estimating them is problematical, but they would increase rather than diminish judging from the Panama Conversion Route; using 1:1 slopes, this plan required 688 million yards, which increased to 917 million when geological slopes were applied.

Any one of these sea-level routes thus might require up to 2,000 million yards of excavation. It is also pertinent to note that they are in isolated locations without terminal ports or harbors, and that the construction problems to be met are uncertain and difficult to appraise. On the credit side any one of them would provide a route supplementary to the present canal, not only far removed from it, but devoid of locks, so that requirements of both security and capacity could be satisfied. It would seem that cost and construction difficulties relative to the other routes—and perhaps political considerations—would be the determinants in deciding whether one of these three crossings would be recommended.

The Nicaragua lock canal has many advantageous aspects. Topographical and geological conditions of the route are well defined. Excavation would be less than for a sea-level canal. On the basis of the 1931 cost estimates, the present cost might be fixed in the neighborhood of $1\frac{1}{2}$ billion dollars. Political considerations are favorable since the Nicaraguan Government has offered complete cooperation. From the standpoint of dispersion, canals in Nicaragua and Panama would satisfy security to the degree that a lock canal can be considered secure; or, stated in another way, to the degree that they increase the difficulty of an enemy to deprive us of a trans-isthmian crossing. This latter consideration is the one to be resolved in deciding for or against recommending the Nicaraguan route.

The Chorrera routes in Panama offer the possibility of a sea-level canal with a minimum of wet excavation. Topographical and geological conditions are reasonably well known, which may or may not be an advantage since they presage expensive harbor and port facilities and total excavation of over $1\frac{1}{4}$ billion cubic yards. A distinct disadvantage is that their construction would require an enlargement of the Canal Zone and removal of one or both terminals from the vicinity of existing Panamanian cities.

The Panama Parallel Route would permit a sea-level canal to be built in the Zone without disturbing the present lock canal. By its construction we would have two canals, although their proximity one to the other would raise the question of complete wartime safety. Construction could be done in the dry, but the building of the barrier dams required to hold back Gatun Lake would be a task of great magnitude, while their breaching in case of attack might put both canals out of service. Relative cost and security from attack are the factors to be considered in choosing this interesting scheme.

Converting the present canal to sea level will entail less total excavation than on any other sea-level route and probably no more than for a lock canal in Nicaragua. Terminal facilities are established and thus do not enter into the future costs. On the other hand, the neces-

sity for dams and diversion channels to control floods in intersected streams and for temporary locks to maintain traffic through the canal during the construction period will add greatly to the expense. If deep dredging is feasible, construction difficulties and costs will be greatly lessened, but even if the alternative of building temporary conversion locks, as required for stage lowering of Gatun Lake, is necessary, no insurmountable troubles are involved. As a matter of fact, the deep-dredging and stage-lowering plans are not mutually exclusive initially. It would be possible to start with either one and then shift to the other after the first 2 or 3 years of preliminary work, without appreciable loss of time or money.

Finally a sea-level canal undoubtedly offers the greatest assurance of security and minimum interruption in wartime, since damage from bomb hits could be repaired by dredges in a matter of days as contrasted with the many months that a lock canal would be out of service if its water supply should be lost. The sea-level canal also promises no real navigation hazards because of tidal currents. Cost is the principal question upon which a recommendation favoring conversion of the present canal to sea level is believed to rest.

Insofar as improving the present lock canal is concerned the Pacific Terminal Lake Plan is the one to be weighed and compared. Building the new, enlarged two-lift locks required, and dispersing them as much as necessary for safety, makes this by no means a low-cost solution. Here, too, relative cost and security will control the decision.

In summary, the choice of the investigators must rest between supplementing the present canal with another removed a safe distance from it or converting the present canal to sea level. After that the choice shifts to Congress and the American people. If they want a safe canal badly enough to invest what it costs—1 billion, 2 billion, perhaps 3 billion dollars—they can have it. If security comes too high, and they will settle for increased capacity, any one of the schemes mentioned earlier in this article for improving the present canal, including completion of the Third Locks Project, will suffice. Upon such a decision rests finally the solution to the puzzle in Panama—and incidentally the silencing or the resurrection of the ghost of a sea-level canal.

CONSULTANTS ON THE WORK

In addition to the staff of the investigation, numerous consultants have been engaged on the work, as mentioned earlier in this article. Most important of these, of course, are the members of the consulting board, which consists of Rear Adm. John J. Manning (C. E. C. USN) Chief of the Bureau of Yards and Docks; Brig. Gen. Hans Kramer (C. E. Retired); Prof. Boris A. Bakhmeteff, Columbia University;

Joel D. Justin, consulting engineer, Philadelphia; W. H. McAlpine, office of the Chief of Engineers, Washington: and H. M. Hill, Northern States Power Co., Minneapolis.

Harvey Slocum, well-known construction specialist, has advised upon construction plans and estimates, while such experts from the office of Chief of Engineers have been called in as Gail A. Hathaway on flood control, Carl Giroux and B. W. Steele on dams and hydro power, and Leon Zach on construction camps and permanent town planning. Soil mechanics and foundation guidance is being supplied by Profs. H. M. Westergaard, Arthur Casagrande, and L. Don Leet of Harvard University, and E. M. Fucik of Chicago. Prof. Roland Kramer of the University of Pennsylvania has made extensive studies and advised upon canal traffic growth.

COMPARISON OF PROPELLER AND REACTION- PROPELLED AIRPLANE PERFORMANCES¹

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INTRODUCTION

Coincident with the development of successful turbojet power plants for aircraft, a broad new field of propulsion has come to light. Power-plant research and development has progressed so rapidly that a wide choice of power plants is now available to the aircraft manufacturer, who as yet has had little opportunity to demonstrate the practical applications. The purpose of this paper is to evaluate the airplane-performance potentialities of four types of widely differing power plants and to indicate their trends and particular fields of application.

Conventional power plants of the reciprocating, internal-combustion type, both direct and indirect air-cooled, have been extended to compounding with a gas-turbine wheel operated by the normal exhaust gases and delivering the power thus generated back into the crankshaft. The independent gas turbine is also available for use in conjunction with the propeller, in which case approximately 80 percent of the energy in the gases is absorbed by the turbine to drive the propeller and the remainder is utilized in the form of reaction propulsion. Air-stream engines include the turbojet, reso-jet (or intermittent duct), and the ram-jet (or athodyd), all of which are reaction motors depending upon atmospheric air supply. A third classification of available power plants consists of dry- or liquid-fuel types of rocket motors, which are distinguished principally by the fact that atmospheric oxygen is not used for combustion as in the case of other power plants.

¹ Presented before a closed meeting of the Institute of the Aeronautical Sciences, Hollywood, Calif., Aug. 15, 1945. Reprinted by permission from the *Journal of the Aeronautical Sciences*, vol. 13, No. 8, August 1946.

For this paper four power plants having distinctly different performance characteristics have been chosen: (1) a V-type, reciprocating, liquid-cooled engine employing water injection for emergency power; (2) a turbojet engine having about 23 percent less sea-level static thrust than the former; (3) a hypothetical subsonic ram-jet; and (4) a bipropellant liquid-fuel rocket motor. For brevity, these power plants will be referred to as a propeller, turbojet, ram-jet, and rocket, respectively.

Because these power plants differ so radically in performance characteristics, it is difficult to determine a sound basis for comparison. It has therefore been decided to design a single-engined, single-place fighter or pursuit type airplane employing each type of power plant and limiting the size to some reasonable weight, say less than 14,000 pounds. It is felt that the results submitted, together with the analysis presented, offer sufficient justification for classifying these types of power plants in specialized categories in which they excel. Thus, if a particular type of engine shows outstanding merit in a high-altitude and high-speed performance for a fighter, similar reasoning may be judiciously applied in considering other aircraft types.

The text is divided into three parts. Part A compares the various types of engines independently of airplane characteristics insofar as possible. Part B briefly describes a logical and practical airplane design configuration for each power plant. In part C, the results of the airplane performance characteristics are presented from which comparisons and conclusions may be advanced.

PART A—POWER-PLANT CHARACTERISTICS

1. *Reciprocating engine and propeller.*—A typical high-performance engine employing water injection is assumed, which delivers 2,000 b. hp. for take-off, the power varying linearly with density to 1,700 b. hp. at an engine critical altitude of 20,000 feet. Typical propulsive efficiencies have been used in converting power to available thrust in order to afford a direct comparison with the other types of power plants in which thrust is the fundamental consideration. Exhaust jet thrust has also been included.

The gas turbine driving a propeller has not been considered because the differences when compared to the remaining three power plants are not radically different from those of the reciprocating engine. Specific engine weight and size are improved, but fuel consumption will be increased in comparison to reciprocating engines. Also, the propeller itself imposes a definite limitation on maximum speed. Both the gas turbine and compound engine may be considered to be alternate developments in relation to propeller-driven airplanes.

2. *Turbojet engine.*—The turbojet engine selected is typical of the single-stage centrifugal blower type employed in a number of aircraft.

Performance characteristics represent those already attainable at the present state of development.

3. *Ram-jet engine*.—Of the four power plants considered, the ram-jet represents the only hypothetical design under consideration, it being the only type of propulsion not actually known to exist as a flight article. As a basis for the theoretical engine performance, the analysis presented in reference 1 is used herein. This type of power plant will not operate at zero air speed, and consequently cannot take off. Auxiliary take-off means are assumed to launch the airplane and accelerate to a flight speed of 350 miles per hour, at which time the ram-jet is started. Since no logical engine output rating exists in this case, a unit of a size suitable for 10,000-pound fighter is assumed.

Combustion temperatures of the order of 3,000° F. are assumed to be structurally possible since moving parts do not exist to complicate the problem. Successful operation in this regime has been demonstrated. Already turbine buckets are operating in a 1,500° F. gas temperature. Kerosene fuel to the engine is provided by a turbine-driven fuel pump.

4. *Rocket motor*.—The rocket motor, being small and light, has been chosen as a 9,000-pound thrust unit, which takes advantage of a high thrust output without presenting impractical arrangement or installation problems. An example of actual application is the well-known German Me 163. For practical reasons an existing type of rocket motor using a bipropellant fuel system has been chosen, leaving room for considerable improvement with further research in the relatively near future.

The problem of supplying the fuel and oxidizer to the motor at high pressure is solved by turbine-operated pumps using the same propellants for power.

5. *Maximum thrust available* (figs. 1-3).—Immediately apparent is the fact that the conventionally powered airplane will have the lowest maximum speed at all altitudes and, also, that it is essentially a low-altitude power plant. Obviously, the ceiling of this airplane will be inferior. Furthermore, the maximum speed limitation is absolute as indicated by the fact that above 600 miles per hour the propulsive efficiency limitation due to compressibility effects causes the thrust available practically to vanish. The slope of the curve indicates good acceleration characteristics in level flight below maximum speed and also that climb characteristics will be relatively good.

Considering the rocket airplane, maximum performance is obviously superior under all conditions. Inasmuch as atmospheric pressure variation is but a small percentage of the motor chamber pressure, the small variation in thrust with altitude has been neglected. Air speed has no effect upon thrust output. At low altitudes only does the ram-jet offer competition in available thrust, but this is offset by the fact that airplane drag at high air densities is also extremely high.

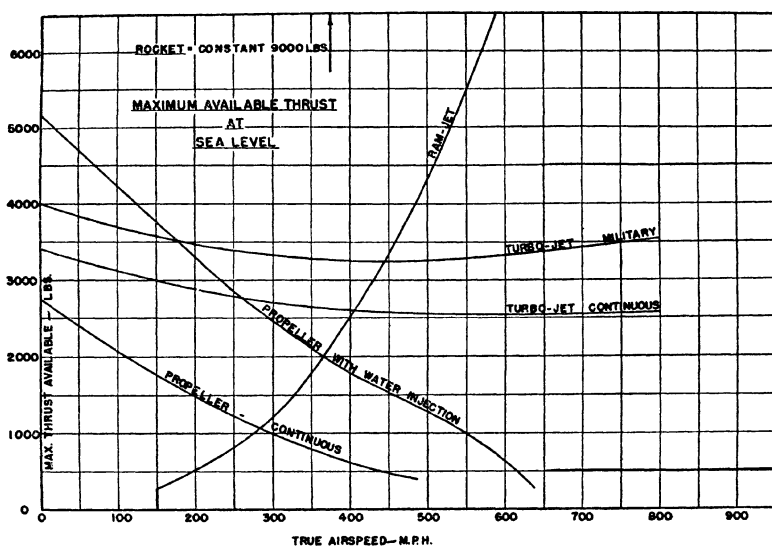


FIGURE 1.—Thrust vs. air speed at sea level.

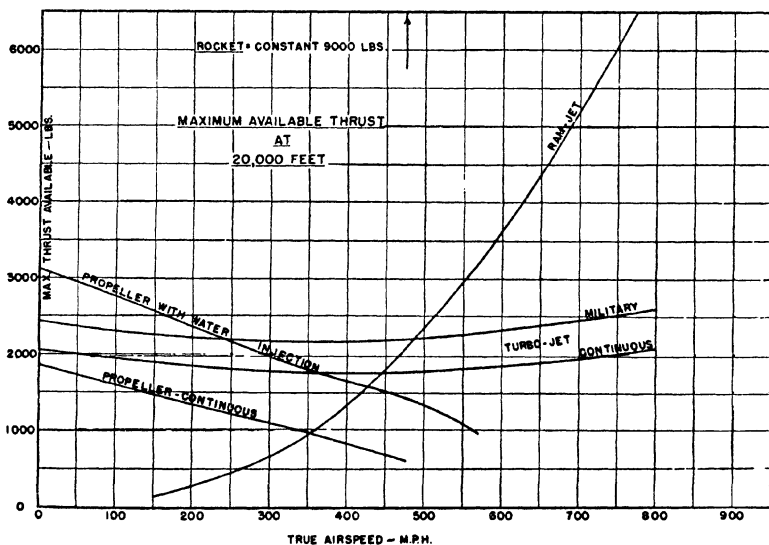


FIGURE 2.—Thrust vs. air speed at 20,000 feet.

Outstanding is the rocket's complete superiority in performance at high altitudes where airplane drag is greatly reduced. Thus, high-altitude speeds will necessarily be outstanding as will also the high rate of climb at all altitudes.

Relatively constant thrust with speed variation is also apparent for the turbojet. In this case output suffers considerably with altitude,

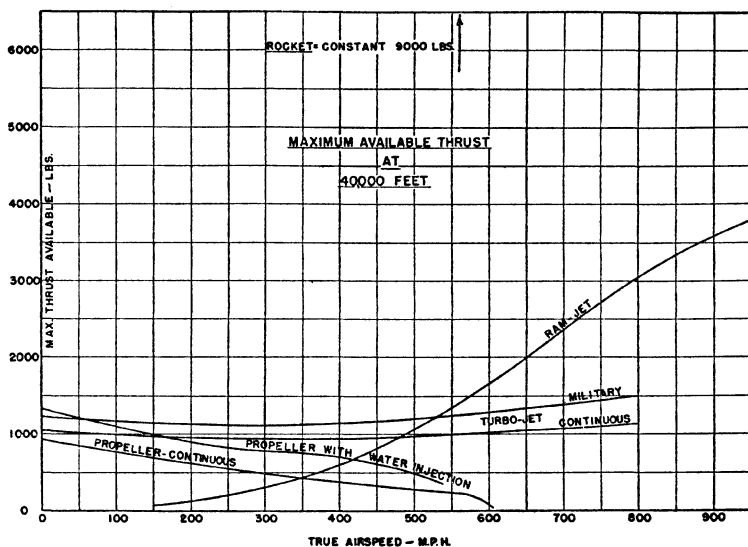


FIGURE 3.—Thrust vs. air speed at 40,000 feet.

but maximum speed performance compared to the propeller-driven airplane affords a sharp contrast.

From the standpoint of self-sufficiency, the ram-jet is the least desirable since an auxiliary means of propulsion is required for take-off. Although thrust varies roughly as the velocity to the 2.0 to 2.5 power, it falls off with atmospheric density. In other words, thrust is a direct function of differential pressure, which, in turn, is determined by the airplane drag characteristics. This results in a relatively low airplane ceiling but an excellent maximum speed at sea level where the air forces become prohibitive for sonic air speeds. Loss of energy due to shock waves in the duct entrance has been taken into account.

6. *Specific engine weight* (fig. 4).—Important in the airplane design configuration is the power-plant installation weight. For comparison, the complete power-plant weight, exclusive of fuel-supply system, per unit of maximum available thrust, is presented in figure 4. (See also sec. 9.) When the reciprocating engine is used for high-altitude operation it becomes an extremely complicated and heavy power plant; in fact, beyond 40,000 feet it becomes prohibitively so. Also, the improvement in specific engine weight with decreasing air speed and altitude again classifies propeller propulsion as best suited for relatively low air speeds and altitudes. Even when compared at low altitudes, the reciprocating power-plant dry weight is some 20 times as heavy as the rocket motor.

The turbojet offers a considerable improvement in engine weight which will probably continue to be improved. Again, with increas-

ing altitude specific engine weight increases, but not to the prohibitive degree evidenced by the propeller type. Also, contrary to the propeller type, specific weight improves at the higher air speeds, which emphasizes the practicability of higher air speeds.

Considering the ram-jet, its design depends to a large extent on both speed and altitude. Marked improvement obtains at higher air speeds, and, when considering the reduction of thrust with altitude, it tends to become bulky and heavy for high-powered, high-altitude application. Apparently, the ram-jet is a medium-low-altitude, high-speed type of power plant.

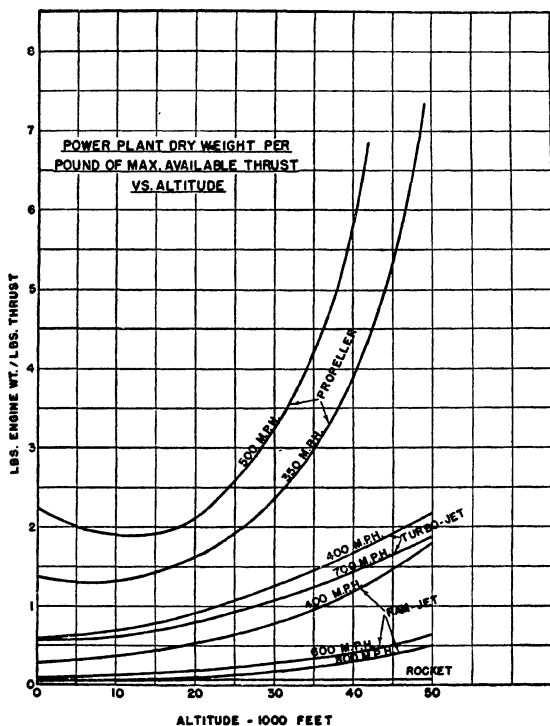


FIGURE 4.—Power plant weight-thrust ratio.

Simplest of all is the rocket, which again makes no compromise for air speed or altitude variation. In terms of specific power-plant weight it is unexcelled.

7. *Specific fuel consumption (S. F. C.) at maximum continuous thrust (fig. 5).*—The propeller-type plant offers a large saving in fuel, especially at the lower air speeds, as evidenced by its specific fuel consumption at maximum continuous thrust rating. At speeds exceeding 500 miles per hour this fuel consumption would become greater than that of the turbojet. However, employing this thrust rating, speeds

much in excess of 400 miles per hour are not obtainable. Curves for both the propeller and turbojet are based upon maximum *continuous* available thrust, which, unlike the ram-jet and rocket, are less than the maximum available as shown in figures 1, 2, and 3. Specific consumption at maximum continuous thrust for the turbojet does not vary significantly with air speed and improves appreciably at the higher altitudes.

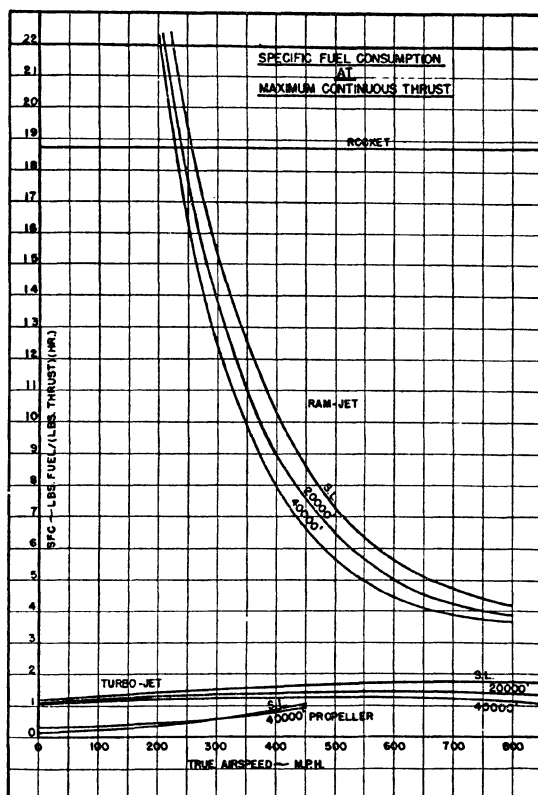


FIGURE 5.—S. F. C. at maximum continuous thrust.

In the case of the ram-jet, an entirely different variation is found. Here, efficient operation is decidedly improved at extremely high speeds, in the region of Mach Number=1.0, while at lower air speeds the fuel consumption is prohibitively high, and, as seen from figures 1, 2, and 3, the maximum thrust available at low air speeds is exceedingly small. Again, the ram-jet clearly belongs to the very high-speed regime.

As usual, the rocket is not influenced by speed or altitude, resulting in a constant, but high, specific fuel consumption, since the oxygen to support combustion must be included.

Selecting S.F.C. values, (lb fuel/lb. thrust times hours), maximum continuous thrust operation for each power plant results in the following comparison:

S. F. C. at maximum continuous thrust

Power plant	Sea level			20,000 feet		
	Actual	Relative	Air speed	Actual	Relative	Air speed
Propeller.....	0.56	1.0	300	0.71	1.0	375
Turbojet.....	1.72	3.1	520	1.46	2.1	520
Ram-jet.....	5.10	9.1	650	5.15	7.2	590
Rocket.....	18.75	33.5	675	18.75	26.4	685

Air speeds corresponding to the four airplanes are included in the table as a matter of interest. A considerable improvement in efficiency at the higher altitude is noted for the last three power plants compared to the propeller and the price that must be paid for increasing air speeds above 500 m. p. h. is painfully evident.

8. *Variation of S. F. C. with reduced thrust* (fig. 6).—Comparison of specific fuel consumption at various level flight speeds is not possible without considering airplane characteristics, because the thrust required depends directly upon the airplane drag. Therefore, the curves drawn in figure 6 necessarily coincide with the particular airplanes to be considered later but the general trends and comparisons are valid in other applications.

Obviously, the best range performer is the propeller, which, at low thrusts, may be operated on a lean mixture. Here the variables, engine revolutions per minute, manifold pressure, degree of supercharging, fuel mixture setting, and engine operating temperatures must all be carefully controlled in order to obtain maximum economy. Nevertheless, a reduction in S. F. C. of the order of 50 percent from that at maximum continuous power represents a decided saving. Based on both figures 5 and 6, the propeller has no serious competitor for maximum range or endurance at moderately low air speeds.

Unlike the propeller, the turbojet evidences a loss in economy when operating at lower than maximum output, representing about a 10 percent increase in S. F. C. for cruising conditions. Cruising S. F. C. is better at high altitudes than at low levels in all cases with the exception of the rocket.

An appreciable improvement in economy of the ram-jet at cruising speeds is shown tending to offset its disadvantage when compared to the turbojet at high speed. Maximum thrust and the corresponding S. F. C. are necessarily established as those produced at the maximum speed of the airplane.

The rocket, as always, appears as the only power plant whose characteristics are independent of its application. In this respect, how-

ever, the individual rocket motor units are operated at their maximum efficiency conditions dictated by design. In other words, a selected number and size of individual rocket motors are chosen so that thrust available exists in steps according to the motors selected during operation.

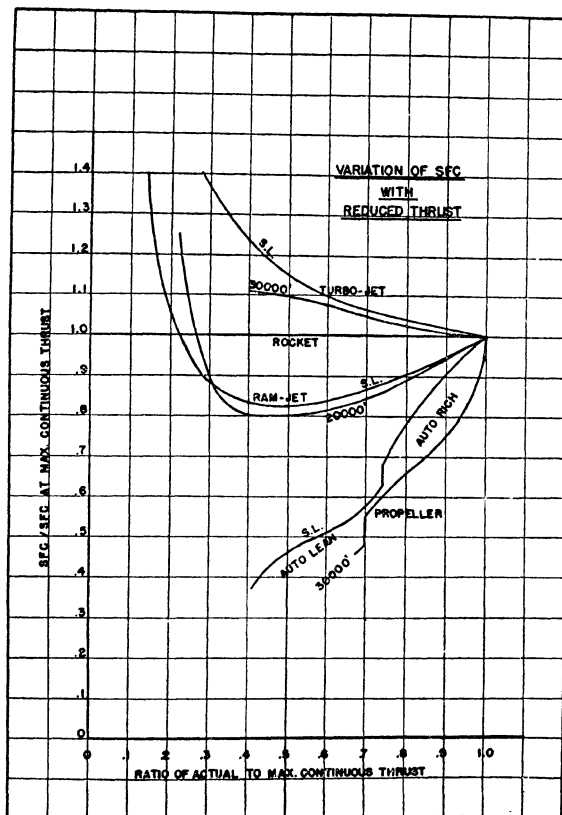


FIGURE 6.—S. F. C. variation with thrust.

Having analyzed the airplane range characteristics, the following table comparing the S. F. C.'s for conditions of maximum range is obtained:

S. F. C. at economical cruising conditions

Power plant	Sea level			20,000 feet		
	Actual	Relative	Air speed	Actual	Relative	Air speed
Propeller.....	0.28	1.0	175	0.32	1.0	225
Turbojet.....	2.18	7.8	325	1.66	5.1	365
Ram-jet.....	4.70	16.8	535	4.43	13.7	500
Rocket.....	18.75	67.0	415	18.75	58.0	425

The influence of part thrust S. F. C. variation from figure 6 is clearly seen. For instance, the opposite cruising trends shown for the turbojet and the propeller increase their relative specific fuel consumptions from 2 or 3 to 1 at maximum continuous thrust to 5 to 8 to 1 at optimum cruising thrust.

Here again, the fact that an enormous sacrifice in economy accompanies premium performance, that is high cruising speeds, is emphasized. Ridiculous comparative S. F. C.'s and cruising speeds for the rocket seem to eliminate this power plant from any consideration involving economical operation.

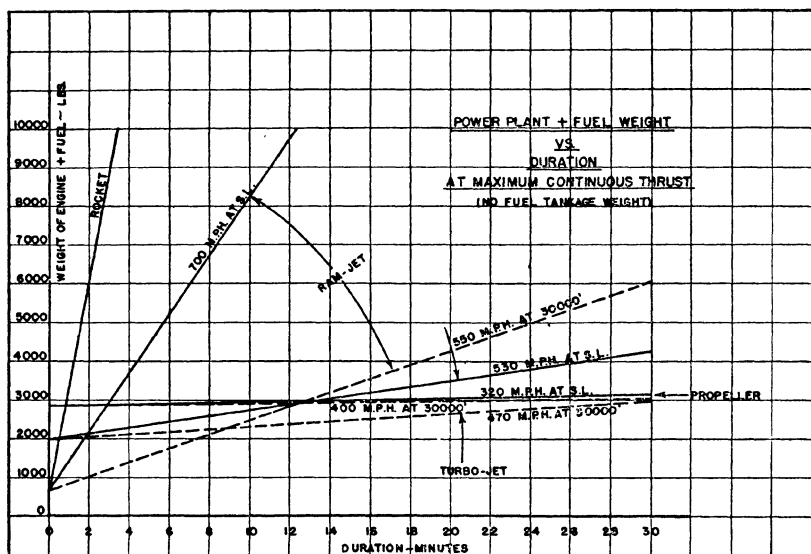


FIGURE 7.—Power plant plus fuel weight.

9. *Power plant plus fuel weight* (fig. 7).—Figure 7 is a plot of power-plant weight plus fuel weight, excluding fuel tanks, taken at maximum continuous rating versus duration. Weights of power plant are assumed as follows:

Power-plant weights

	Propeller	Turbojet	Ram-Jet	Rocket
Motor + controls and plumbing.....	1,900	2,000	550	450
Cooling system + coolants.....	450	0	0	0
Propeller.....	500	0	0	0
Turbine and pumps.....	0	0	150	225
Total pounds.....	2,850	2,000	700	675

For the rocket motor the power plant plus fuel weight is startling, being 10,000 pounds for less than 4 minutes duration, with no weight allowance for fuel tankage. However, when the vastly superior thrust rating is considered the picture improves somewhat.

Investigations have revealed clearly the fact that for any given airplane and gross weight, the minimum pounds of fuel expended per 1,000 feet of altitude gained in climbing always occurs at the maximum available thrust. This phenomenon is valid irrespective of compressibility drag increases. Consequently, an extremely high thrust rocket compared to the other power plants has been chosen because it is practical to do so in this case where the power-plant specific weight is small. The tremendous amount of energy available in an extremely short period of time provides dazzling performance for a decidedly limited duration. Even under maximum range operating conditions at vastly reduced thrust the high S. F. C. still obtaining irrevocably limits range and endurance. The only possible recourse would be some means of launching or commencing rocket flight at high altitudes where exceptionally high air speeds will offset the high rate of fuel consumption. Thus, rocket-powered flight in the present instance is considerably limited in range.

Next comes the ram-jet, in which case the fuel consumption depends directly upon speed and altitude. Assuming a maximum speed of 700 miles per hour at sea level and 550 miles per hour at 30,000 feet, it is apparent that at low altitudes a substantial, though not large improvement over the rocket obtains. At altitude, the fuel consumption is not a great deal more than the propeller or turbojet-propelled airplanes. In this case 10,000 pounds of power plant plus fuel results in a practical average duration of 30 minutes. Generally, it may be concluded from the figure that the ram-jet is suitable for relatively high maximum speeds at medium to low altitudes for relatively short duration.

By virtue of a lower power-plant weight the turbojet excels over the propeller up to 15 minutes at sea level and 30 minutes at 30,000 feet, after which the propeller takes over. Considering the decided advantage of speed for the former, it may be generalized that for excellent high-speed performance at all altitudes up to 40,000 feet, the turbojet endurance at maximum continuous thrust is a good half-hour. To compare with the rocket and ram-jet a 10,000-pound power plant would show an average duration of some 135 minutes, or $2\frac{1}{4}$ hours.

The propeller and internal-combustion engine is by far the best power plant for long endurance at maximum continuous power but at a considerable sacrifice in speed. Extrapolating an average curve to a 10,000-pound power plant results in an endurance of about 12 hours. Note that the ram-jet and turbojet show an increased economy at altitude as does the propeller, but the latter is the only one to show an improvement in high speed at altitude.

10. *Power plant plus fuel volume* (fig. 8).—In addition to power-plant weight its size is also a critical factor in the design of the aircraft

Figure 8 shows the volume of power plant plus fuel corresponding to the weights shown in figure 7. Power-plant volumes are the volumes occupied by the units if wrapped with cloth. In other words, power plants having an odd shape will result in still more space unusable for other airplane components. Power-plant volumes in cubic feet are estimated as follows, representing the minimum space not available for other airplane components:

Power-plant volumes

	Propeller	Turbojet	Ram-jet	Rocket
Engine, blower and gear box.....	33.....	95.....	235.....	9.....
Air ducting.....	14.....	25.....	0.....	0.....
Turbine and pumps.....	0.....	0.....	5.....	5.....
Oil and coolant systems.....	13.....	0.....	0.....	0.....
Total.....	60 ft. ³	120 ft. ³	240 ft. ³	14 ft. ³
Equivalent frontal diameter.....	38 in.....	52 in.....	50 in.....	18 in.....
Frontal area.....	5.5 ft. ²	14.8 ft. ²	13.6 ft. ²	1.8 ft. ²

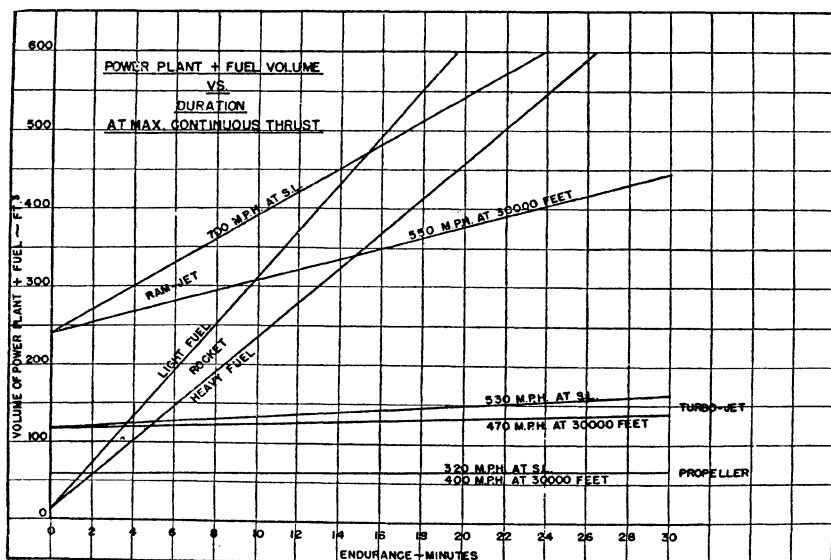


FIGURE 8.—Power plant plus fuel volume.

In comparing the engine volumes, the power plants in order of preference are the rocket, propeller, turbojet, and ram-jet. Fortunately, although the last-named has a considerable volume, its weight and installation considerations are such that it is practical to convert the aft fuselage, which always is relatively vacant because of balance considerations, into the power plant proper. Tending to offset this effect is the fact that the large mass airflows consumed dictate large duct inlet scoops. The simplicity of mechanisms alleviates installation problems considerably.

Next in bulky space requirements is the turbojet, nearly one-quarter of the volume of which is compressor entrance air supply ducting in an average installation. This feature requires a relatively large nacelle or, because of the weight and diameter, dictates the fuselage size and arrangement in a single-engined airplane.

Although the internal-combustion engine is small, the space requirements are nearly doubled by carburetor, oil cooler, and Prestone radiator air scoops and ducting. Fortunately, the main component parts, the engine, oil coolers, and Prestone coolers, may be disposed about the airplane structure to best advantage.

The rocket motor is by far the smallest and simplest from the design standpoint. Air-intake ducts are always a problem, and at high flight speeds considerable research is necessary before satisfactory solutions will become available. In the case of the rocket, no air is taken aboard for the power plant, thus eliminating this problem. Note that the total rocket motor volume equals only the air ducting required for the reciprocating engine and that the power plant consists of two simple components that may be located at the designer's discretion.

In the frontal area comparison both air-stream engines will dictate the fuselage maximum cross section; the conventional engine and cooling system will definitely have an influence upon this design feature, but the rocket eliminates this problem.

Referring to figure 8, the additional volume required by the fuel is indicated by the slope of the curves. Here again, the rocket is critically limited in duration. Following in increasing order of preference are the ram-jet, turbojet, and propeller. Fuels are gasoline at 6 pounds per gallon for the propeller, kerosene at 6.7 pounds per gallon for both air-stream engines, and equivalent densities of the combined fuel and oxidizer for the rocket of from 8.4 to 11.2 pounds per gallon depending upon the fuels chosen.

11. *Engine air requirements* (fig. 9).—In designing air-intake ducts the relative problems are indicated by the engine air requirements shown in the figure for maximum thrust conditions, which would represent take-off, climb, and high-speed operation.

Since the ram-jet curves approximate a straight line through the origin, the scoop entrance velocity will be a relatively constant percentage of airplane speed. Volume of airflow is extremely large, indicating difficult problems to be solved.

The turbojet evidences only a slight increase in air consumption with air speed, indicating that the optimum entrance duct efficiency for a fixed entry will depend upon the conditions selected in the design. Again, large airflows must be handled. In the case of both air-stream engines the ram drag due to taking this air aboard has been subtracted from gross jet thrust to arrive at the maximum thrust available as shown in figures 1, 2, and 3.

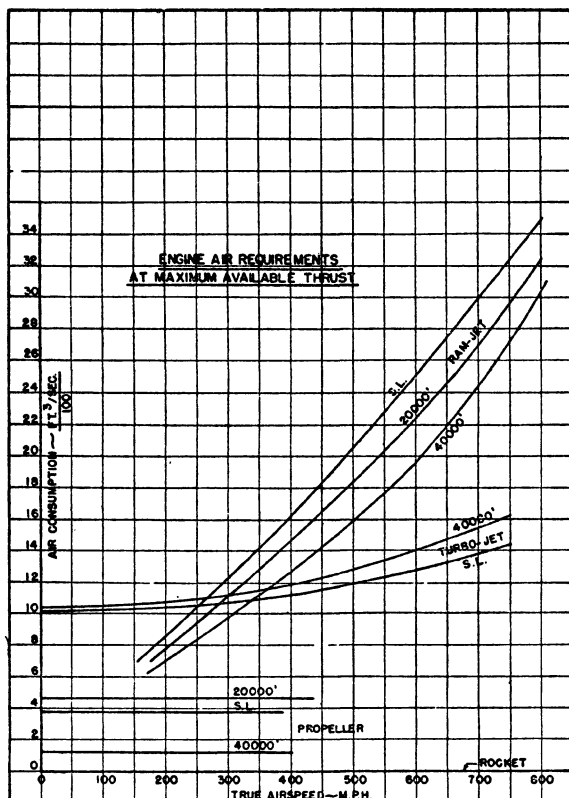


FIGURE 9.—Engine air requirements.

Cooling air requirements for the propeller type represent about 80 percent of the total shown. Constant air volume requirements dictate scoop design for particular conditions, generally for maximum speed.

In the case of the rocket no air is required.

PART B—AIRPLANE DESIGNS

Since the characteristics of the four power plants are extremely diversified, it is difficult to determine which type is most suitable for a given application until each is translated into an airplane-design study and the respective performances are evaluated. As the majority of the power plants potentially represent premium performance aircraft at a sacrifice in pay load, it is reasonable to use a fighter or interceptor-type airplane as a basis for comparison. This represents the type of military application where performance is decidedly at a premium and economy and practicability are sacrificed as a matter of self-preservation. Arbitrarily, for expediency in the comparison, these aircraft will be considered as single-place, single-engined air-

craft having conventional wing and tail arrangements, conventional pilot accommodations, and internal fuel only.

Figures 10-13 show the general arrangements and physical characteristics of the airplanes and table 1 lists the weight break-downs. Less armament is carried by the two airplanes whose range and duration of combat are obviously restricted. Unit wing weight depends greatly upon thickness, and structure in general is affected by the operational speed ranges, which affect the design air loads. Landing-gear weight is primarily influenced by the gross weight at landing condition.

TABLE 1.—*Component weights*

	Propeller	Turbojet	Ram-jet	Rocket
Wing.....	1,230	1,550	1,100	1,100
Tail.....	170	200	260	260
Fuselage.....	660	1,100	700	970
Landing gear.....	600	680	400	450
Power plant:				
Motor.....	1,660	1,850	550	400
Accessories.....	1,150	130		50
Controls.....	40	20	10	10
Fuel system.....	600	840	1,050	550
Turbine and pumps.....	0	0	140	210
Fixed equipment:				
Armament.....	1,100	1,100	700	700
Controls.....	140	230	200	200
All other.....	460	700	290	200
Weight empty, pounds.....	7,800	8,400	5,400	5,100
Pilot.....	200	200	200	200
Fuel, oil and coolant.....	1,500	3,400	4,400	8,200
Gross weight, pounds.....	9,500	12,000	10,000	13,500

A practical limit to the internal fuel capacity appears to be about 200 gallons of high-octane gasoline in self-sealing fuel tanks for this size of propeller-driven fighter. Laminar flow wings of 15 percent thickness are employed. A nominal wing loading of the order of 35 to 40 pounds per square foot represents a present-day compromise between performance on the one hand, and maneuverability and serviceability with respect to tactical airfield considerations on the other. Armament load is 1,100 pounds.

Because of the disadvantageous fuel-consumption characteristics of the turbojet and also the considerably increased high-speed regime of operation, this type of airplane is forced to higher wing loadings, in this case of 50 pounds per square foot, resulting in a greater difference between take-off and landing wing loadings. Wing thickness of 13 percent compromises internal fuel capacity with low drag characteristics. In this case, also, leak-proof fuel tanks for kerosene are a necessity. Fuel here represents about 31 percent of the take-off gross weight compared to 16 percent in the case of the propeller, resulting in landing wing loadings of 35 and 33 pounds per square foot, respectively. The same 1,100-pound provision is allowed for armament.

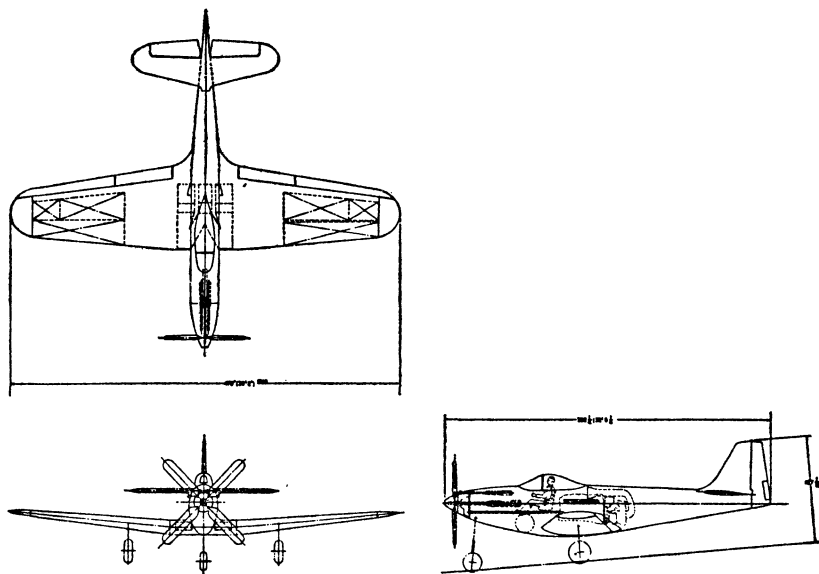


FIGURE 10.—Propeller airplane. Gross weight, 9,500; wing area, 250; take-off W/S, 38; landing W/S, 33; wing section, 65-215; aspect ratio, 6; wing incidence, 1.5° ; fuel load—gal., 200; fuel load—lbs., 1,200; wing span, 39'2"; fuselage length, 32'8"; vertical height, 10'7".

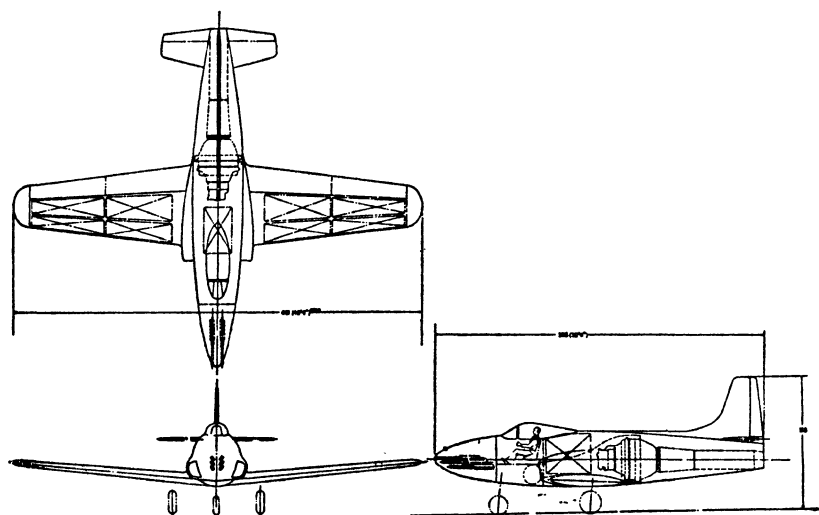


FIGURE 11.—Turbojet airplane. Gross weight, 12,000; wing area, 240; take-off W/S, 50; landing W/S, 35; wing section, 65-113; aspect ratio, 7; wing incidence, 1.5° ; fuel load—gal., 500; fuel load—lbs., 3,350; wing span, 40'11"; fuselage length, 32'11"; vertical height, 12'9".

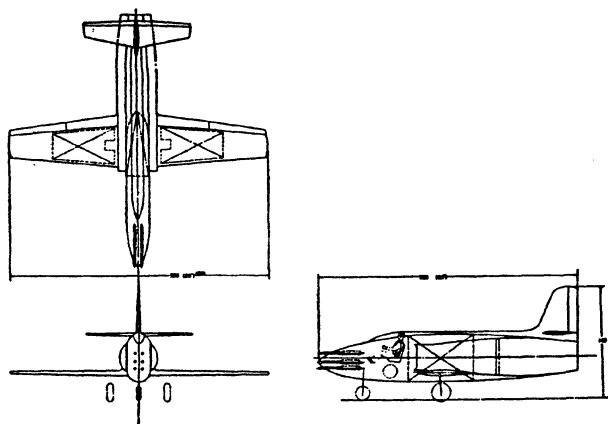


FIGURE 12.—Ram-jet airplane. Gross weight, 10,000; wing area, 130; launching W/S , 77; landing W/S , 42; wing section, 65-110; aspect ratio, 6; wing incidence, 1.0° ; fuel load—gal., 655; fuel load—lbs., 4,400; wing span, 28'; fuselage length, 28'; vertical height, 12'4".

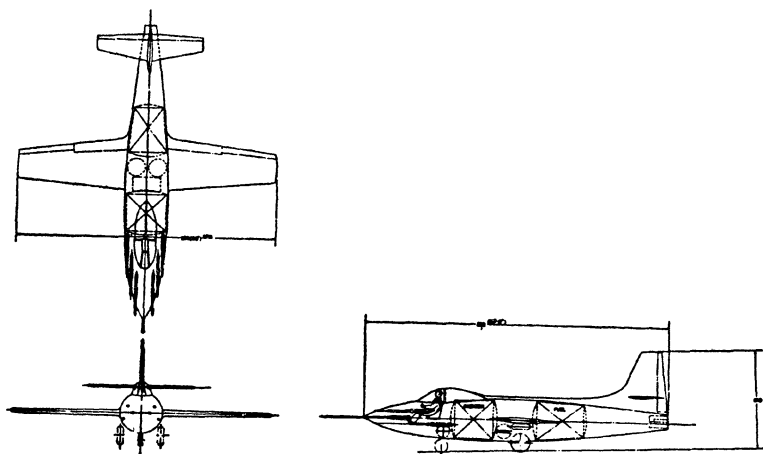


FIGURE 13.—Rocket airplane. Gross weight, 13,500; wing area, 130; take-off W/S , 104; landing W/S , 40; wing section, 65-110; aspect ratio, 6; wing incidence, 2.0° ; fuel load—gal., 985; fuel load—lbs., 8,200; wing span, 28'; fuselage length, 32'8"; vertical height, 10'10".

In the design of the ram-jet airplane, the combustion chamber cross-sectional area dictates the fuselage size. Because of high fuel consumption 44 percent of the launching gross weight represents fuel carried in both the fuselage and wing. Kerosene is assumed as fuel carried in self-sealing tanks. Since the flight duration and range are limited, this airplane is adaptable only to defensive strategy, and, if self-sealing tanks are eliminated, a consequent improvement will be

afforded by the addition of some 10 percent in fuel. Some compromise wing loadings must be chosen. In this case 77 pounds per square foot for take-off represents a relatively low wing loading for this type of airplane but is assumed to allow for auxiliary means of take-off and flight up to 350 miles per hour, at which point the ram-jet power plant is started for the first time, take-off obviously not being possible with the ram-jet alone. The resultant landing wing loading of 42 pounds per square foot is quite reasonable.

High performance dictates reduction in wing thickness to 10 percent.

As is obvious from the phenomenal fuel consumption, the rocket-motor-powered airplane must carry an abnormal amount of fuel, in this case 8,200 pounds, or 61 percent of the take-off gross weight. Wing loading is dictated primarily by the landing condition and has been held at 40 pounds per square foot, resulting in 104 pounds per square foot for take-off, which seems entirely feasible. Since super-performance is obvious, aerodynamic considerations dictate the entire arrangement. A practicable wing thickness of 10 percent for the wing and 8 percent for the tail are chosen. As in the case of the ram-jet, 700 pounds of armament are installed. Tanks are not self-sealing owing to the nature of the fuels, the extremely short duration, and the exceptional performance. All fuel is carried in the fuselage.

PART C—PERFORMANCE COMPARISONS

1. *Calculation of airplane drag.*—Drag estimates for all four airplanes are based upon an identical analysis wherein the wetted areas of the component parts are assigned drag coefficients depending upon fineness ratios, Reynolds Numbers, and Mach Numbers. In this manner, the drag coefficients of the component parts are obtained and adjusted for lift coefficient or angle of attack. The cleanliness factors, C_f —the parasite drag coefficient based upon total wetted area at $C_L=0$ and $RN=8 \times 10^6$, and the parasite drag coefficients, based upon wing area, are given in the following table:

Cleanliness factor and drag coefficients

	Wetted area	C_f	S	C_D
Propeller.....	931	0.0038	250	0.014
Turbojet.....	881	.0034	240	.013
Ram-jet.....	672	.0035	130	.019
Rocket.....	645	.0034	130	.017

Both the turbojet and the rocket exhibit extremely good aerodynamic cleanliness, being about an 11-percent improvement over the propeller airplane. Drag coefficients based on wing area are shown in which high wing loadings, because of the relatively large fuselages, result

in high parasite drag coefficients. The airplane drag coefficient for the propeller should be increased to 0.015 to allow for cooling drag at high speeds.

Of the utmost importance is the effect of compressibility on drag above the critical speed, which depends upon body shape and altitude. Ballistic data have been useless to the airplane designer because of the complete neglect of aerodynamic characteristics as such, the blunt projectile trailing edge shapes, and generally the extremely high Mach Number regimes of projectile flight.

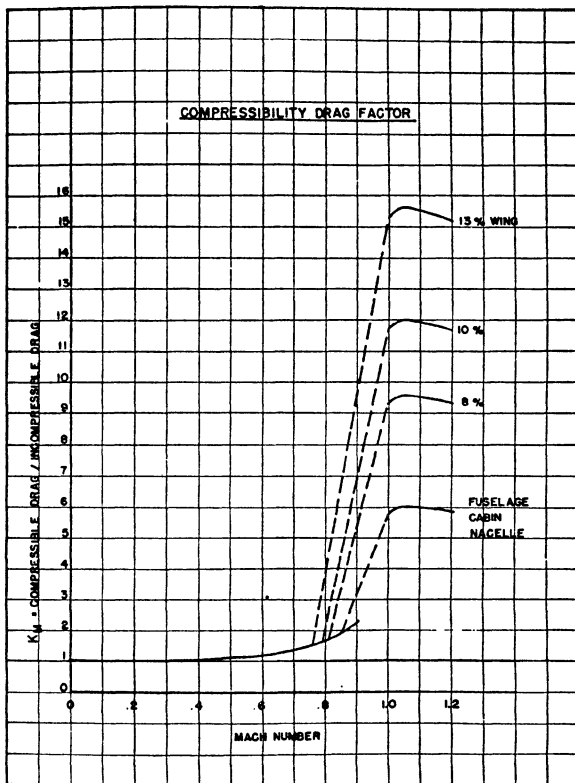


FIGURE 14.—Compressibility drag multiplication factor.

Reference 2 provides the basis for the compressibility drag multiplication factor used for wings. This factor is multiplied directly times the airplane drag calculated on the above basis neglecting shock wave effects. These factors, assumed to vary directly as wing thickness as shown in figure 14, are 15.6, 12.0, and 9.6 for 13, 10, and 8 percent thick laminar flow airfoils at $M=1.0$. In the case of a fuselage, representing a more compact three-dimensional body, a corresponding value of 6.0 has been assumed.

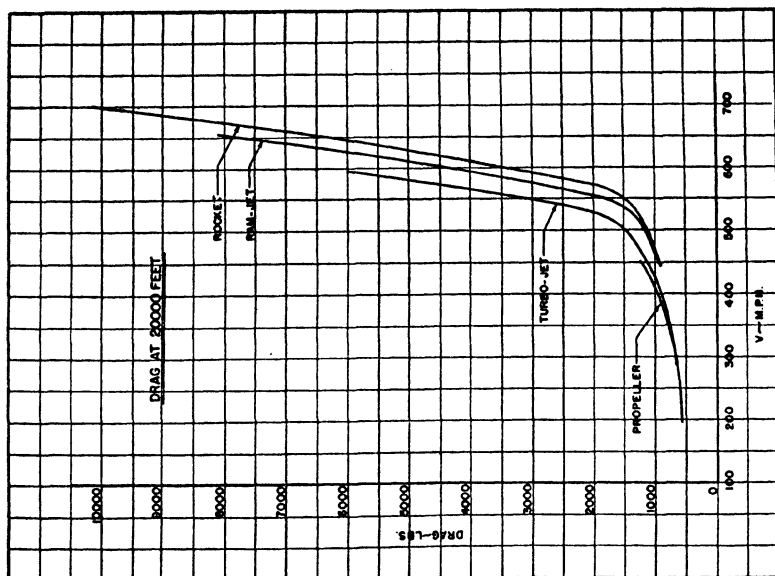


FIGURE 15.—Airplane drag at sea level.

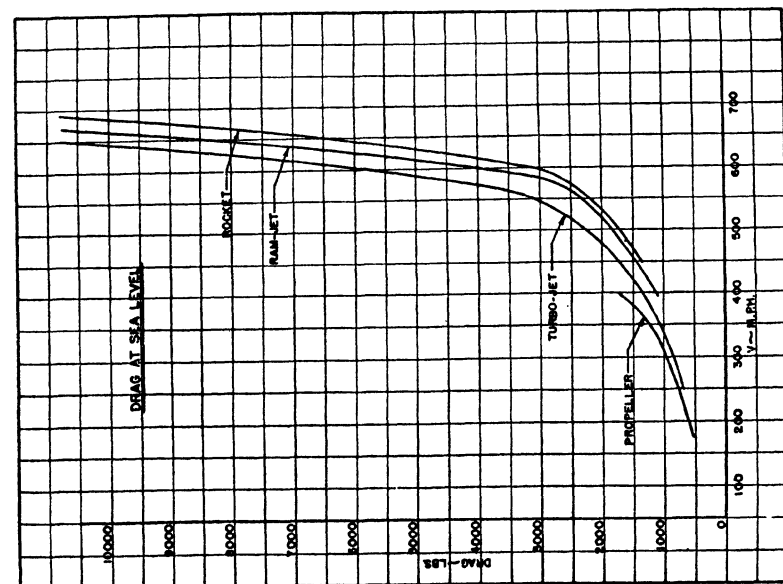


FIGURE 16.—Airplane drag at 20,000 feet.

Finally, the total airplane drag vs. true air speed is depicted in figures 15, 16, and 17. These curves, together with those in part A of this paper, provide the necessary data for the performance evaluations given below.

The drag curves shown are for the highest airplane weights obtaining after climbing to the respective altitudes. Gross weight variation has been taken into account wherein performance is affected.

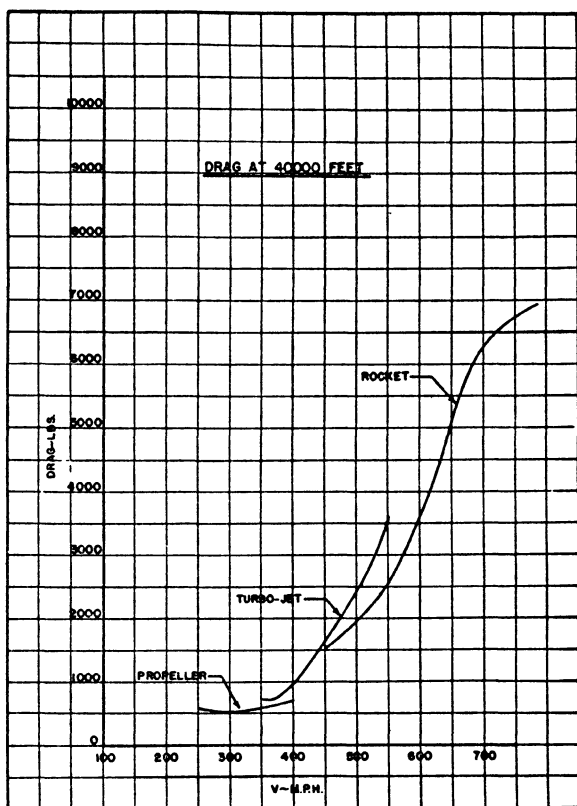


FIGURE 17.—Airplane drag at 40,000 feet.

2. *Maximum speeds and best climbing speeds* (fig. 18).—Maximum speed of the propeller airplane is 480 miles per hour at 25,000 feet, indicating that the practical high speed limit for this type of propulsion will not greatly exceed 500 miles per hour. At all altitudes up to 40,000 feet a speed greater than 400 miles per hour is attainable, although 400 miles per hour at sea level seems slow for ground-strafting work. Best climbing air speed is relatively low, being 50 to 55 percent of maximum level flight speed between sea level and critical altitude, respectively.

Next in high speed comes the turbojet, which excels the propeller at all altitudes, being 37 percent faster at sea level and 8 percent at 25,000 feet, the top speed of 550 miles per hour representing a decided advantage. Maximum speed for this airplane occurs at sea level only because of the influence of Mach Number on drag. Otherwise, a considerable increase in speed with altitude up to 20,000 to 30,000 feet would be found. Although at altitudes between 25,000 and 40,000 feet the speeds are not greatly in excess of those for the propeller, this margin will improve with further development of turbojet engines.

A Mach Number = 1.0 line is shown in the figure, representing the magic barrier to speed performance, being the condition of maximum airplane drag coefficient. In order to achieve sonic velocity, the thrust

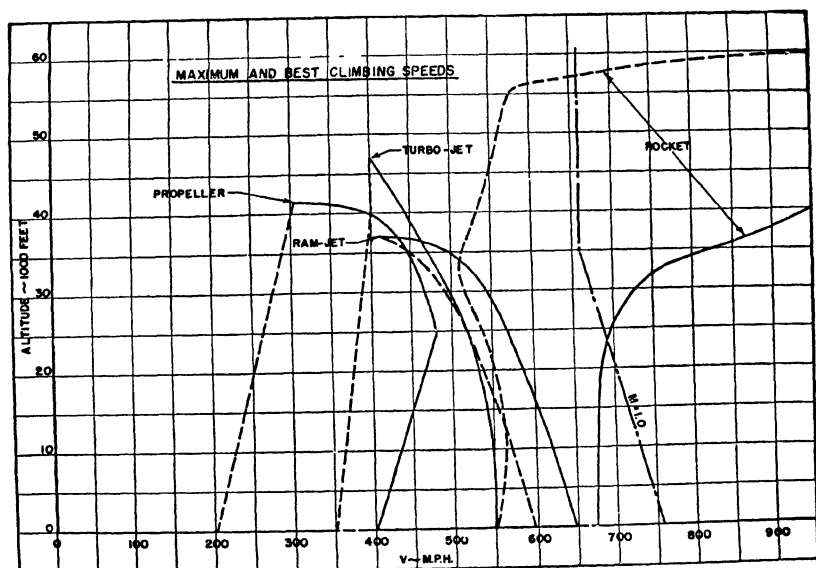


FIGURE 18.—Maximum and best climbing speeds.

required at sea level would be 1,000 percent of that for the speed actually attained or 650 percent in the case of a 30,000-foot altitude. Sonic velocities with this type of airplane, therefore, appear impossible at the present time.

Regarding speed for best climb, which occurs at 65 percent of maximum speed at sea level and 75 percent at 20,000 feet, a considerable tactical advantage over the propeller airplane is realized. A greater distance covered during climb, since rates of climb for both are comparable, also offers a considerable advantage in being able to protect a given target from a base relatively far distant. An appreciable performance margin also obtains above 40,000 feet because of the higher ceiling of the turbojet airplane.

Turning to the ram-jet airplane, it is astonishing to note that its speed for best climb considerably exceeds the turbojet's maximum speeds at all altitudes up to 33,000 feet, but that its ceiling is quite low. Maximum speed, 650 miles per hour, occurs at sea level, and the Mach Number limitation on speed is obvious in the figure. Climbing speeds are about 90 percent of the maximum speeds.

Although the ram-jet engine is hypothetical, and is undoubtedly optimistic, it is interesting to note that 270 percent of the actual thrust at 650 miles per hour at sea level is required to reach a Mach Number of 1.0. Because of the fact that thrust increases greatly with speed, this represents an engine of 190 percent greater power. Because of the impracticability of such high air speeds at high air densities, sonic speeds may be regarded with considerable pessimism in this case also. Nevertheless, from the standpoint of maximum speed alone, the ram-jet excels the turbojet by as good a margin as the latter excels the propeller.

The rocket airplane excels in speeds at all altitudes by a wide margin. At sea level the ram-jet is capable of competing for high speed, and at altitudes up to 30,000 feet it also is similar in speed for best climb. Since the rocket thrust remains constant, the rocket airplane is capable of increasing its Mach Number with increase in altitude until it reaches sonic velocity at about 24,000 feet. Thereafter maximum air speed increases rapidly with altitude, the maximum limitation being imposed purely by the available fuel.

Speed for best climb is of interest, showing a best climbing speed at approximately constant Mach Number up to the tropopause. Beyond this altitude the lower drag resulting from lower air densities enables the best climbing speed to increase until at about 57,000 feet Mach Number 1.0 is reached. Beyond this altitude, of course, performance is dictated entirely by the available fuel consideration.

3. *Rates of climb and ceilings* (fig. 19).—Maximum rates of climb for both the propeller and turbojet airplanes are similar. The latter, however, climbs at a much higher air speed, giving it a considerable advantage in combat in that it therefore can determine the conditions of engagement in combat or terminate it at will. The absolute ceiling of 47,000 feet, compared with 41,500 feet, also adds to this advantage. Climb and speed calculations for the propeller airplane are practically independent of the small fuel consumption, while in the case of the other three airplanes gross weight has necessarily been reduced according to the rate of fuel consumption. It should be noted that the larger fuel load in percent of gross weight for the turbojet will result in appreciable improvement in climb performance during tactical operation.

Again, the excellence of low-altitude performance is noted for the ram-jet airplane. Since its thrust falls off with air density, its ceiling

is found to be low. The extremely high climbing speeds should be taken into consideration in tactical operations.

The rocket airplane shows amazing rates of climb at all altitudes, varying from 28,500 feet per minute at sea level to 66,500 feet per minute at 60,000 feet, where it runs out of fuel. This airplane will coast to about 75,000 feet. Rate of climb reduces considerably at 35,000 feet, because of the reduced speed for best climb, resulting in less thrust horsepower available at constant thrust. As climbing speeds approach and exceed $M = 1.0$, these powers become extremely large. For instance, 57,000 feet and 660 miles per hour in climb represents 16,000 thrust horsepower. Climb performance has been

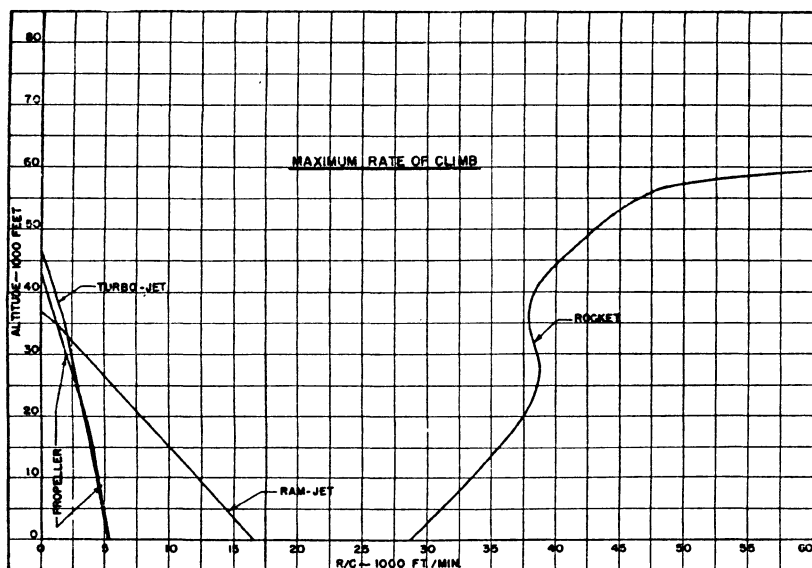


FIGURE 19.—Maximum rate of climb.

integrated and weight variation accounted for, including that required for linear acceleration along the flight path.

Time to climb and absolute ceiling may be compared in the following table, where the rocket ceiling is given as that altitude at which fuel is exhausted.

Time to climb, and ceiling

	Time (minutes) to climb to—			Absolute ceiling
	20,000 feet	30,000 feet	40,000 feet	
Propeller.....	4.9	9.0	19.0	43,000
Turbojet.....	4.7	8.3	14.3	47,000
Ram-jet.....	1.6	3.3	-----	37,000
Rocket.....	.6	.9	1.1	60,000+

4. *Range* (figs. 20 and 21).—In determining range and climb performance the amount of fuel consumed in climb is important, except in the case of the propeller. The following table compares the fuel consumptions in climb.

Fuel consumed during climb

Sea level to—	Propeller		Turbojet		Ram-jet		Rocket	
	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent
10,000.....	135	11.2	220	6.7	860	19.5	2,950	36.0
20,000.....	185	15.2	350	10.4	1,200	27.2	3,700	45.3
30,000.....	240	19.7	480	14.4	1,600	36.0	4,360	53.1
40,000.....	290	24.1	620	18.7	-----	-----	5,190	63.2
50,000.....	-----	-----	-----	-----	-----	-----	5,950	72.5
60,000.....	-----	-----	-----	-----	-----	-----	7,650	92.1

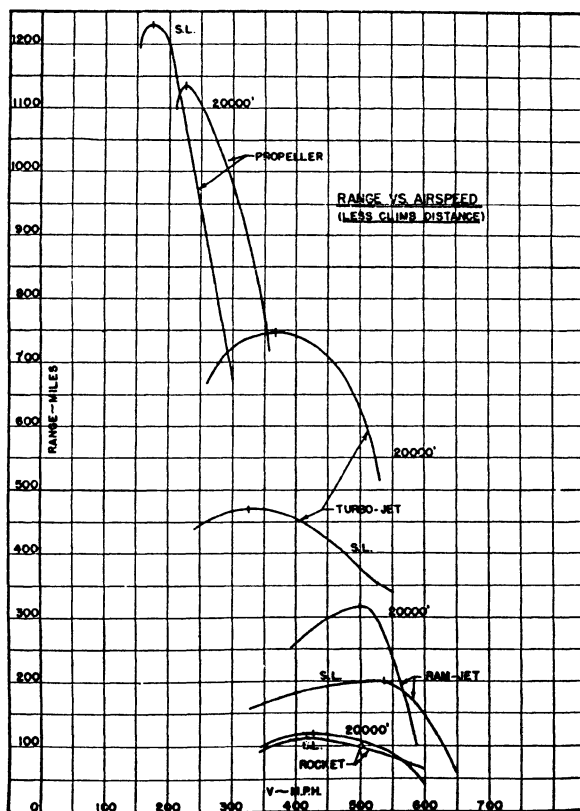


FIGURE 20.—Range vs. air speed.

As seen from the table, the gross weight change for the propeller is small and for practical purposes may be neglected. Fuel expenditure for the ram-jet is not comparable with the others in that take-off and acceleration to 350 miles per hour is accomplished by auxiliary means, for which no allowance has been made. Both the ram-jet and rocket are extremely uneconomical. The rocket necessarily suffers in climbing to higher altitudes where it becomes most efficient, while the ram-jet is essentially a low-altitude airplane. Although the turbojet burns

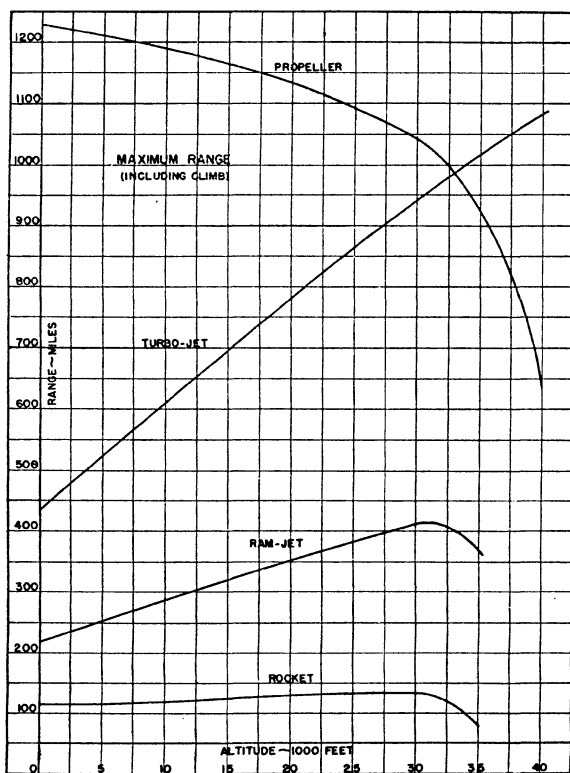


FIGURE 21.—Range vs. altitude.

more fuel in climb than the propeller, a greater percentage of fuel remains after the climb, owing merely to the fact that fuel is a much larger percentage of the gross weight.

Referring to figure 20, the range versus air speed at sea level and at 20,000 feet is shown, which does not include the distance traveled in climb. Although the propeller has greatly superior maximum range, it obtains at an extremely low air speed (200 miles per hour), and a limited range of speeds. At 20,000 feet and the same air speed (350 miles per hour), the propeller and turbojet are equal in range.

Maximum range for the turbojet, although considerably less than for the propeller, occurs at 150 miles per hour faster air speed, or a 45-percent reduction in time for equivalent range. Speed for best range increases with altitude in both cases. An outstanding characteristic of the turbojet is its relative insensitivity to air speed insofar as range is concerned, the only power-plant variable being engine revolutions per minute. In the case of the propeller, as previously mentioned, a number of variables must be carefully controlled within close limits to attain optimum range.

The ram-jet suffers still greater in range, but maximum range occurs at extremely high air speeds, above 500 miles per hour. In this case only, speed for economical operation decreases with altitude.

Range characteristics for the rocket indicate a wide speed range, 350 to 500 miles per hour, with an exceedingly limited range, about 100 miles.

Figure 21 shows the variation in maximum range with altitude, including the distance traveled during climb. The relative maximum ranges and the altitudes at which they occur, up to 40,000 feet, are compared:

Maximum range

	Range		Altitude
	Actual	Relative	
Propeller.....	1,220	9.4	Sea level
Turbojet.....	1,080	8.3	40,000
Ram-jet.....	420	3.2	30,000
Rocket.....	130	1.0	30,000

Whereas the propeller has the greatest range, it occurs at sea level. At altitudes above 35,000 feet, range for the turbojet is superior. Both air-stream engines and the rocket show maximum range increases with altitude of from 18 percent to 250 percent, contrary to the propeller.

CONCLUSIONS

1. *Propeller airplane.*—(a) A practical maximum speed limitation not much in excess of 500 miles per hour is apparent. Maximum speeds obtain in the 20,000- to 30,000-foot range.

(b) Because of superior range, the propeller type of propulsion cannot be supplanted at the present time. Maximum range is relatively insensitive to altitude up to engine critical altitude.

(c) Greater pay loads possible in addition to range make commercial application and long-range bombers most attractive.

(d) Cruising and climbing speeds are slow.

(e) Operation above 40,000 feet appears impractical except possibly in the case of power plants incorporating the gas turbine.

(f) Maximum rate of climb occurs at sea level.

(g) Further improvements, adaptations, and variations will be widely developed in terms of compound and gas-turbine engines and various combinations of them.

2. *Turbojet airplane*.—(a) High maximum speeds where relatively short range is required make this airplane mandatory for military application. Maximum speed occurs at sea level.

(b) Again, for short-range premium operation in commercial fields this power plant is attractive. Range improves markedly with altitude, and economical cruising speeds are relatively high.

(c) Relatively high operating altitudes, at least up to 50,000 feet, are feasible. At high altitudes respectable range is obtained.

(d) Maximum speed of the order of 550 to 600 miles per hour and above at sea level is ideally suited for air-to-ground military operation.

(e) Maximum rate of climb occurs at sea level.

(f) Speeds for maximum rate of climb are reasonably high.

3. *Ram-jet airplane*.—(a) Maximum speed, of the order of 650 miles per hour, occurs at sea level.

(b) Climbing speeds are exceptionally high, being within 5 to 10 percent of maximum level-flight speeds.

(c) Range is extremely limited, representing some 50 percent of that for the turbojet, and also increases considerably with altitude.

(d) Maximum rate of climb at sea level is exceptionally high, but falls off rapidly with increase in altitude, resulting in a rather low ceiling, below 40,000 feet.

(e) Auxiliary take-off means are required.

(f) Performance characteristics indicate that the ideal application would be in the field of low-altitude, flat trajectory missiles against such targets as battleships and aircraft carriers in particular. Air launching would probably be more practical than surface launching.

4. *Rocket airplane*.—(a) This is the only man-carrying airplane capable of flight at supersonic speeds, which distinguishes this type of propulsion from the others considered.

(b) Range is extremely limited and increases slightly with altitude.

(c) As in the case of maximum speed, so also does rate of climb increase phenomenally with altitude.

(d) Ceiling, speed, and climb performance are limited only by the amount of fuel it is possible to carry.

(e) Performance characteristics indicate ideal application to missiles following a trajectory. Peak altitudes greatly exceeding the capability of any other man-made mechanisms are possible. Missile ranges can be vastly extended.

(f) Highly specialized applications in terms of research airplanes and interceptors are evident. A research airplane could be used to conduct tests in level flight for application to high-speed and diving

problems encountered on other types of airplanes. Target-seeking interceptor missiles powered by rocket motors should be most effective.

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